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Commencement Bay Nearshore/Tideflats Remedial Investigation. Summary Report

Tetra Tech, Inc., Bellevue, WA

Prepared for

Washington State Dept. of Ecology, Olympia

Aug 85

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SUMMARY REPORT
FOR THE
COMMENCEMENT BAY NEARSHORE / TIDEFLATS REMEDIAL INVESTIGATION

AUGUST, 1985

PREPARED FOR:
WASHINGTON STATE DEPARTMENT OF ECOLOGY
AND U.S. ENVIRONMENTAL PROTECTION AGENCY

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Olympia, Washington

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TC-3752
Final Report

SUMMARY REPORT FOR THE COMMENCEMENT BAY NEARSHORE/TIDEFLATS REMEDIAL INVESTIGATION

by

Tetra Tech, Inc.

for

Washington State Department of Ecology and
U.S. Environmental Protection Agency

Mr. James D. Krull, Project Manager
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Olympia, Washington

August, 1985

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This report summarizes work complete under the U.S. EPA/WDOE Cooperative Agreement for the Commencement Bay Nearshore/Tideflats Remedial Investigation of the Waterways/Shoreline area. The Commencement Bay Superfund Investigation includes various integrated program management and technical components. These include assessments of chemical contamination, biological effects, toxicitiy, and public health concerns; identification of sources; and identification of potential remedial actions and technologies. Methods and approaches used to conduct the investigation are included in Section 2 of this summary report. Results are presented and descussed in Section 3. These sections include an assessment of environmental factors (i.e., sediment contamination, toxicitiy, biological effects), an assessment of public health risks from consumption of contaminated seafood, identification and prioritization of problem areas and contaminants, evaluations of contaminant sources, and identification of potential remedial actions and technologies. In Section 4, high-priority areas are identified and potential remedial actions are recommended. An overview of contamination and biological effects in the entire study area is presented in Section 5. A retrospective evaluation of the study design and recommendations for future studies are presented in Section 6.

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1. INTRODUCTION

1.1 BACKGROUND

On October 23, 1981, the U.S. Environmental Protection Agency (EPA) announced an "interim priority list" of 115 top-priority hazardous waste sites targeted for action under Superfund as authorized under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). Commencement Bay, located in the southern Puget Sound region, was listed as the top priority site in the state of Washington, and was grouped within the 10 highest priority sites in the nation under consideration for federal funding of necessary remedial action under CERCLA. At that time the Commencement Bay site was divided into four areas: the Deepwater, the Nearshore, the Tideflats Industrial, and the South Tacoma channel. On December 30, 1982, the U.S. EPA proposed additions to the national priority list. These additions increased the list to 418 hazardous waste sites ranked by their potential threat to public health and the environment. On this subsequent Superfund list, the Nearshore and the Tideflats Industrial areas of Commencement Bay were designated as a separate project, as was the South Tacoma channel, while the Deepwater area was eliminated as a priority site because water quality studies indicated less contamination in that area than was initially suspected. On September 6, 1983, U.S. EPA published and promulgated the first official National Priority List (NPL) of 406 hazardous waste sites, including the Commencement Bay Nearshore/Tideflats area.

On April 13, 1983, the U.S. EPA announced that an agreement had been reached with the Washington Department of Ecology (WDOE) to conduct a remedial investigation of the hazardous substance contamination in the Nearshore/Tideflats Industrial areas of Commencement Bay. Under the Cooperative Agreement, the WDOE was delegated the lead role in the investigation.

The project consisted of two distinct parts: chemical contamination (metals) of the upland environment near the ASARCO smelter (Ruston/Vashon tasks), and chemical contamination and its effects in the marine environment (Waterways/Shoreline tasks). This report deals with the Waterways/Shoreline tasks.

1.2 SITE DESCRIPTION

Commencement Bay is an embayment of approximately 9 square miles in southern Puget Sound, Washington (Figures 1 and 2). The bay opens to Puget Sound to the northwest, with the city of Tacoma situated on the south and southeast shores. Residential portions of northeast Tacoma and the Browns Point section of Pierce County occupy the north shore of the bay. Ownership of the shoreline is vested in the Port of Tacoma, the city of Tacoma, Pierce County, the state of Washington, the Puyallup Indian Tribe, and numerous private parties. Much of the publicly owned land is leased to private industrial and commercial enterprises.

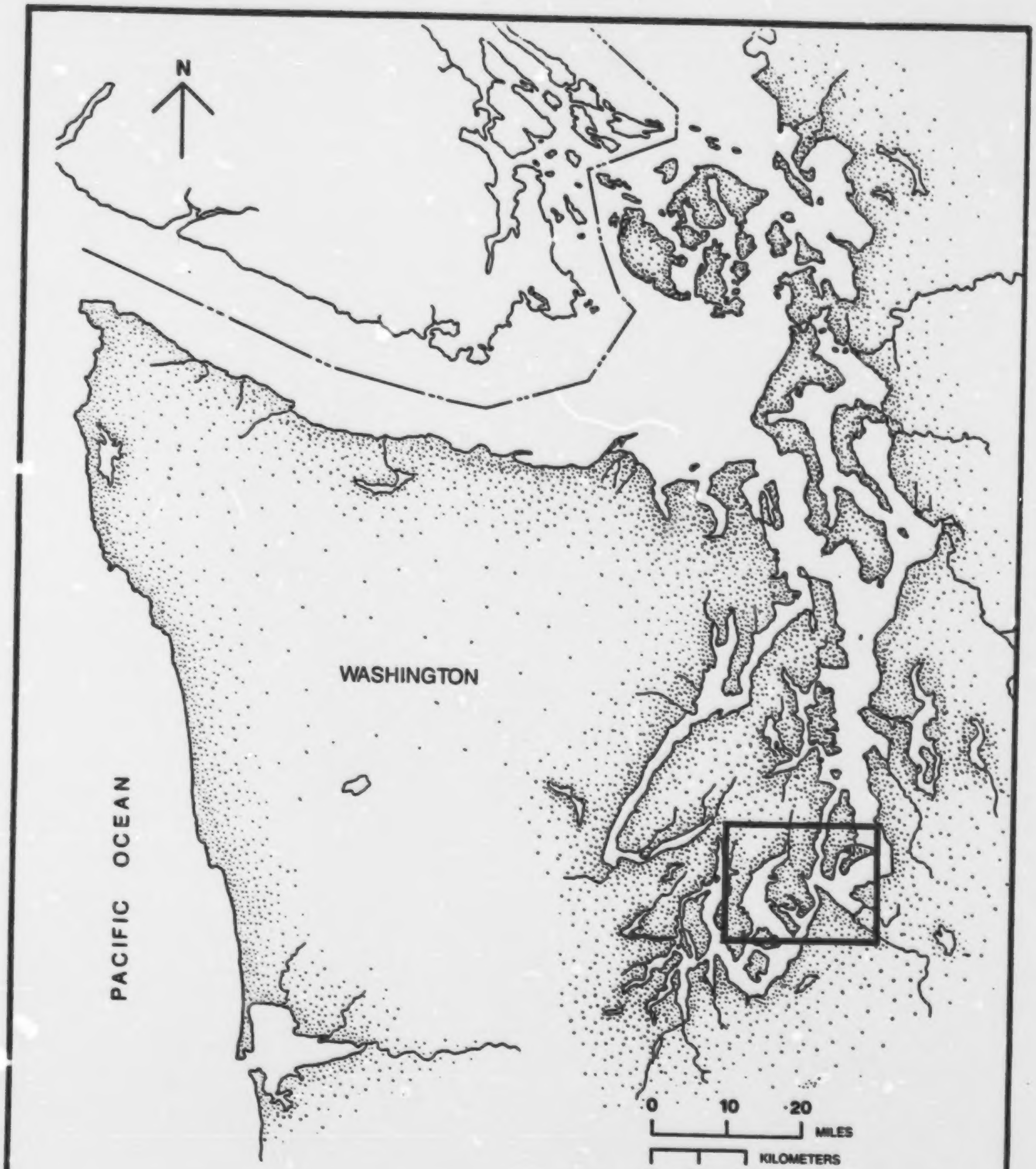
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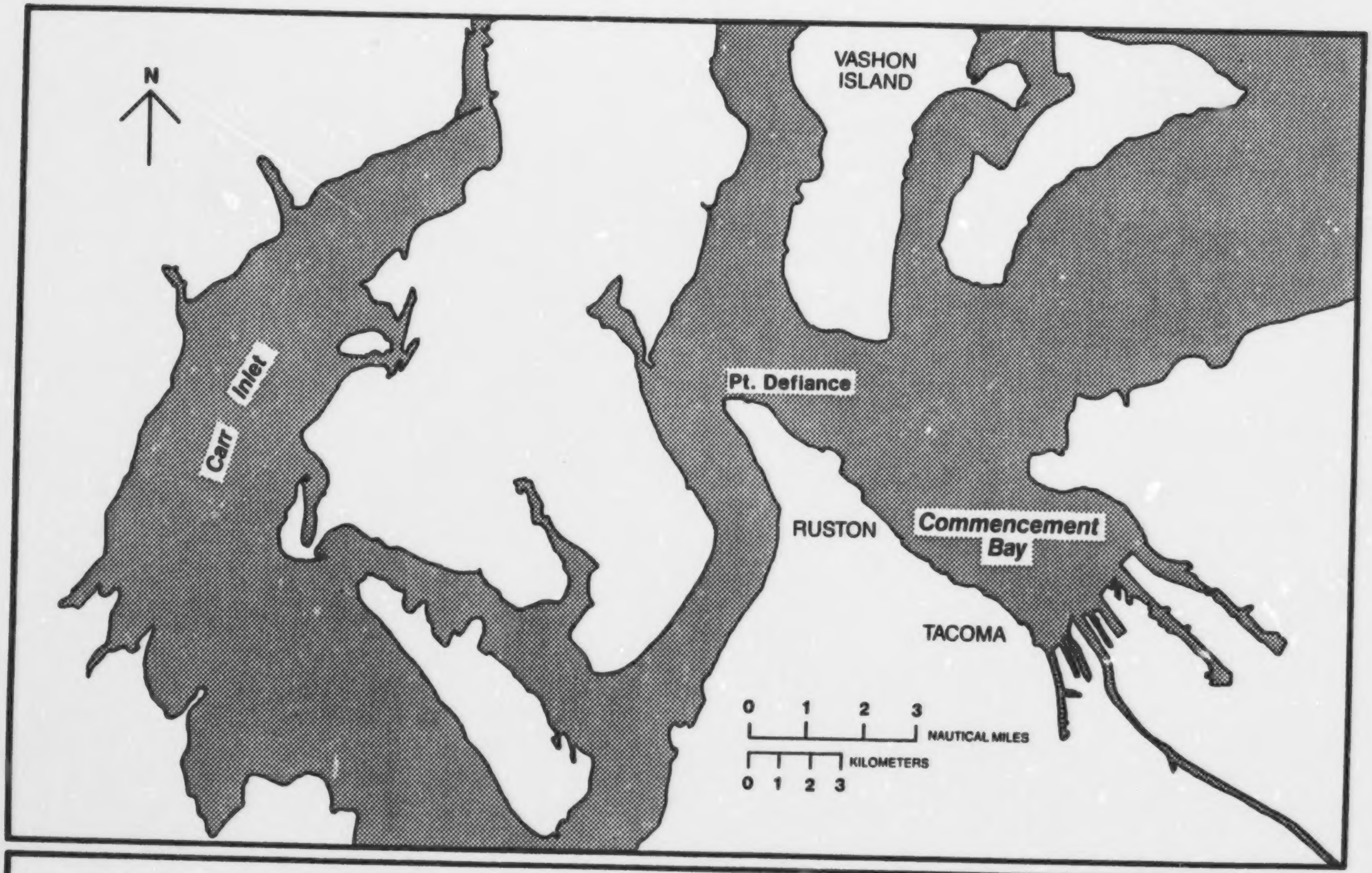
Figure 1. General location of study area in Puget Sound.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VASHON ISLAND
Pt. Defiance
Carr Inlet
RUSTON
Commencement Bay
TACOMA
0 1 2 3
NAUTICAL MILES
KILOMETERS
0 1 2 3

Figure 2. South and southcentral Puget Sound showing locations of Commencement Bay and Carr Inlet.

The project area has been defined as the area along the Ruston Way shoreline from the head of City Waterway to Point Defiance, and the waterways including Hylebos Waterway, Blair Waterway, Sitcum Waterway, Milwaukee Waterway, St. Paul Waterway, Middle Waterway, City Waterway, and the Puyallup River as far upstream as the Interstate-5 highway bridge (Figure 3). The waterward boundary of the project was established at the 60-ft water depth contour. The project boundaries are shown in Figure 3.

1.3 NATURE AND EXTENT OF PROBLEM

Urbanization and industrial development of the Commencement Bay area began in the late 1800s. At that time, the south end of the bay was primarily tideflats formed by the Puyallup River delta. Since their inception in the 1920s, dredge and fill activities have significantly altered the estuarine nature of the bay. The intertidal areas were covered and the meandering streams and rivers were channelized. Numerous industrial and commercial operations were located in the newly filled areas of the bay, including pulp and lumber mills, shipbuilding, shipping, marinas, chlorine and chemical production, concrete production, aluminum smelting, oil refineries, food processing, automotive repair services, railroad operations, and a number of other storage, transportation, and chemical manufacturing companies. The documented waste management practices of these operations included direct and indirect discharges, landfills, open dumps, chemical recycling and reclamation, and on-site storage and treatment facilities. A smelter (ASARCO) has been located in the Nearshore area close to Ruston since the late 1800s. The plant, operational until March, 1985, generated substantial amounts of slag containing various metals. This slag has been deposited along the shoreline near the plant and has been used as fill, riprap, and ballast material in the Tideflats area. The slag has also been used to produce commercial sandblasting material used widely in the study area.

Since initial industrialization of the Commencement Bay area, hazardous substances and waste material have been released into the terrestrial, freshwater, groundwater, and marine environments. Discharges and dumping of solid, liquid, organic, and inorganic waste materials, and contamination from airborne wastes entering via surface and groundwaters have modified the chemical quality of the waters and sediments in many portions of the area. These pollutants include metals (e.g., arsenic, lead, zinc, copper, and mercury) and organic compounds [e.g., polychlorinated biphenyls (PCBs), dibenzofurans, chlorinated pesticides, plasticizers (phthalates), and products of incomplete combustion of fuels (PAH)].

Investigations initiated by NOAA in 1978 and subsequent investigations by others raised concerns over chemical contamination and possible biological effects of this contamination in the area. The pollutant loadings in Commencement Bay originate from both point and nonpoint sources. Point sources include wastes from approximately 27 NPDES-permitted discharges (including two sewage treatment plants). Nonpoint sources include two creeks; the Puyallup River; over 300 storm drains, seeps, and open channels; groundwater seepage, atmospheric fallout, and spills or releases to the environment. The most recent information indicates that there are over 425 potential pollutant sources within the study area.

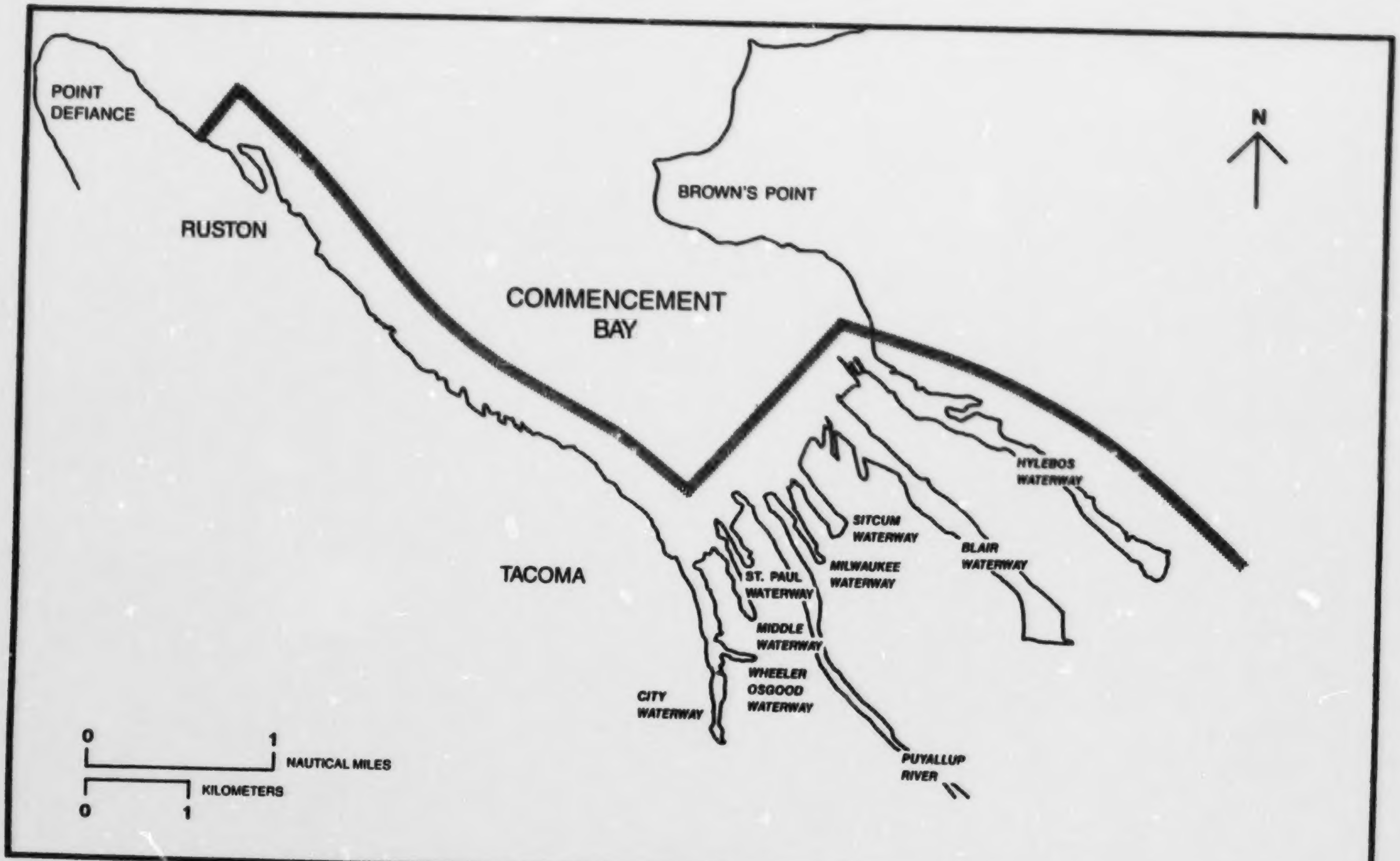
POINT DEFIANCE
RUSTON
BROWN'S POINT
COMMENCEMENT BAY
TACOMA
N
HYLEBOS WATERWAY
SITCUM WATERWAY
BLAIR WATERWAY
MILWAUKEE WATERWAY
ST. PAUL WATERWAY
MIDDLE WATERWAY
WHEELER OSGOOD WATERWAY
CITY WATERWAY
PUYALLUP RIVER
0
1
NAUTICAL MILES
KILOMETERS
0
1

Figure 3. Commencement Bay Nearshore/Tideflats study area.

Previous investigations of the nearshore waters of Commencement Bay have indicated that the highest concentrations of certain metals (arsenic, copper, lead, and mercury) are found in sediments from the waterways and along the southwest shore near the ASARCO smelter. Sediment contamination by persistent organic compounds (e.g., PCBs) has been detected in the heavily industrialized waterways and along the Ruston-Pt. Defiance Shoreline.

Commencement Bay, like much of Puget Sound, supports important fishery resources, especially anadromous salmonid populations. Although occupying Commencement Bay for only part of their life cycle, these species have critical estuarine migratory and rearing habitat requirements. The Commencement Bay area also supports recreational fisheries including pollock, hake, rockfish, and cod. In addition, many other important fishes and invertebrates (e.g., English sole and crab) live in contact with the bottom sediments, resulting in a high potential for uptake of sediment-associated contaminants. Concern has existed over the potential human health impacts from the consumption of local seafood organisms that contain chemical contaminants. The Tacoma-Pierce County Health Department issued an advisory on fish consumption in January, 1983 advising against any consumption of bottom fish from Hylebos Waterway and against regular consumption of bottom fish from the other waterways.

1.4 COOPERATIVE AGREEMENT

Under the U.S. EPA/WDOE Cooperative Agreement, the general objective of the work was to identify the worst problems and to provide a database and framework for future activities. The ultimate goal of the Superfund project was to define the extent of contamination and to remedy public health or environmental threats in a prioritized manner. The remedial investigation concentrated on sediment contamination, effects on biota, and the sources of contamination. The overall scope of work for the remedial investigation included the following tasks:

Task 1. Investigative Support
Task 2. Develop preliminary remedial objectives (Approach to Decision Criteria)
Task 3. Determine the type and extent of contamination and exposure pathways
Task 4. Determine the sources of contamination and characterize as current or historical
Task 5. Endangerment assessment support
Task 6. Identify potential remedial technologies
Task 7. Safety plan; quality assurance/quality control plan.

The following objectives were set for the remedial investigation:

- Define a problem sediment
- Apply definition of problem sediment to delineate problem areas
- For problem areas, determine problem chemicals
- For problem chemicals, determine problem sources

- Prioritize problem areas, problem chemicals, and problem sources
- Assess impacts of fish and crab consumption on human health
- Document alternative methods of dredging, handling, and disposing of contaminated sediments
- Initiate a decision-making framework for managing the disposal of contaminated sediments
- Identify potential remedial alternatives.

1.5 REPORT OVERVIEW

This report summarizes work completed under the U.S. EPA/WDOE Cooperative Agreement for the Commencement Bay Nearshore/Tideflats Remedial Investigation of the Waterways/Shoreline area. The Commencement Bay Superfund investigation includes various integrated program management and technical components. These include assessments of chemical contamination, biological effects, toxicity, and public health concerns; identification of sources; and identification of potential remedial actions and technologies. Methods and approaches used to conduct the investigation are included in Section 2 of this summary report. Results are presented and discussed in Section 3. These sections include an assessment of environmental factors (i.e., sediment contamination, toxicity, biological effects), an assessment of public health risks from consumption of contaminated seafood, identification and prioritization of problem areas and contaminants, evaluations of contaminant sources, and identification of potential remedial actions and technologies. In Section 4, high-priority areas are identified and potential remedial actions are recommended. An overview of contamination and biological effects in the entire study area is presented in Section 5. A retrospective evaluation of the study design and recommendations for future studies are presented in Section 6. References are listed in Section 7.

2. APPROACH AND METHODS

2.1 MANAGEMENT

2.1.1 Program Management

2.1.1.1 Introduction--

The Washington State Department of Ecology (WDOE) is responsible for implementing the U.S. EPA/WDOE Cooperative Agreement for the Commencement Bay Nearshore/Tideflats Superfund site. WDOE is responsible for the execution, administration, and management of the agreement and for the performance of remedial investigation activities. The U.S. Environmental Protection Agency (EPA) Region X provides oversight of activities conducted under the Cooperative Agreement.

2.1.1.2 WDOE Management--

In order to carry out its responsibilities under the Cooperative Agreement, the WDOE appointed a project manager, Mr. James D. Krull, to administer and provide WDOE technical oversight for the remedial investigation. WDOE's management approach included contractual agreements with other agencies and with consulting firms, use of internal WDOE resources, and support from headquarters and Region X of the U.S. EPA.

Respective agency/contractor roles and responsibilities for each of the seven tasks conducted under the cooperative agreement are listed in Table 1. WDOE recognized that effective project management was crucial to complete this multi-task, multidisciplinary investigation and contracted with Tetra Tech, Inc., Bellevue, Washington for overall technical and program management support. Tetra Tech's management approach was based upon continuous communication and effective quality assurance/quality control (QA/QC). This approach ensured that contractors understood the WDOE program objectives and fully recognized the goals, resources, schedules, and legal and regulatory constraints of the program.

2.1.1.3 Management Tools--

WDOE and Tetra Tech recognized that multidisciplinary, politically sensitive, and relatively short-duration programs, such as the Commencement Bay remedial investigation, require technical coordination and open communication among all project participants to ensure that all work is technically sound, legally defensible, on time, and within budget. Major management tools included use of a Technical Oversight Committee (TOC), use of an Internal Oversight Committee within WDOE, contractor monthly progress reports, quarterly progress reports to U.S. EPA, and frequent project review meetings.

The TOC was established to recognize the involvement of many local agencies and authorities and the existence of many other ongoing studies in Commencement Bay Superfund activities. The TOC provided a mechanism

TABLE 1. AGENCY AND CONTRACTOR RESPONSIBILITIES UNDER THE COOPERATIVE AGREEMENT

Cooperative Agreement Task	Agency/Contractor	Responsibility
Task 1 - Investigative Support	Tetra Tech, Inc.	Project management Data management Community relations support Contract procurement Quality control Technical oversight Health and safety program plan
	Tacoma-Pierce County Health Department	Implementation of community relations plan
Task 2 - Preliminary Remedial Objectives	Tetra Tech, Inc.	Development of decision-making criteria for establishing the existence of a signficant threat to public health, welfare, and the environment
Task 3 - Determine Type and Extent of Contamination and Exposure Pathways	Tetra Tech, Inc.	Data evaluation and preliminary study design
	Brown and Caldwell/ E.V.S. Consultants	Final sampling and analysis plan Final quality assurance project plan
	E.V.S. Consultants	Preliminary sediment quality survey Geophysical survey
	U.S. EPA Contract Laboratory Program	Laboratory support
	U.S. EPA Region X/WDOE Manchester Laboratory	Laboratory support
	Tetra Tech, Inc.	Conduct of final field sampling program Data evaluation Quality assurance Report production
	Subcontractors:	
	E.V.S. Consultants	Bioassays, cruise support
	Raven Systems Research	Logistics support
	AB Consulting	Quality assurance
	Evans Hamilton	Benthic investigations, cruise support
	University of Washington	Taxonomic sorting and identification
	FWHC	Fish pathology
	Port of Tacoma	Blair Waterway investigation

TABLE 1. (Continued)

Task 4 - Determine Sources of Contamination and Characterize as a Current or Historical Source	Washington State Department of Ecology - Water Quality Investigations Section	Point and nonpoint source investigations Quality assurance
	U.S. EPA Contract Laboratory Program	Laboratory support
	U.S. EPA Region X/WDOE Manchester Laboratory	Laboratory support
	Tacoma-Pierce County Health Department	Drainage survey and mapping
	Tetra Tech, Inc.	Data evaluation, technical oversight, report production
	JRB Associates (SAIC)	Source investigations, prioritization of sources, potential responsible parties
Task 5 - Endangerment Assessment	U.S. EPA Headquarters Contract Support - Versar, Inc.	Assessment of human health risk from ingestion of fishes and crabs
	Tacoma-Pierce County Health Department	Human Toxicology support, community relations
Task 6 - Identify Potential Remedial Technologies	U.S. Army Corps of Engineers, Seattle District and Vicksburg Waterways Experiment Station	Dredging techniques, treatment and disposal alternatives for contaminated sediments Decision-making framework for disposal of dredged materials
	Tetra Tech, Inc.	Identification of potential remedial technologies and specific remedial actions Feasibility study work plan
Task 7 - Additional Requirements	Tetra Tech, Inc.	Quality assurance program plan Health and safety guidelines Audits and reporting for quality assurance, and health and safety.

for transfering information related to Commencement Bay, and acted as a scientific review and advisory panel. TOC members and their affiliations are listed in Table 2. The TOC met on an as-needed basis with at least one meeting every three months. All major project reports were reviewed by the TOC.

2.1.1.4 Major Management Decisions--

Two management decisions made early in the project by WDOE in conjunction with U.S. EPA had a large impact on the direction and scope of the project. The first was to rely on existing groundwater contamination data in the project area rather than using limited project funds to install networks of monitoring wells and conduct the associated analyses. This decision allowed resources to be focused on defining and prioritizing problem areas in and sources of contaminants to waterways. If potential groundwater sources were identified, resources to further investigate these sources could then be focused on areas of need. The second decision was to use the U.S. EPA Superfund Contract Laboratory system for the majority of the chemical analyses needed for the project. This service was provided outside of the existing project budget and allowed a dramatic increase in the areal coverage of the project and sampling station density.

2.1.2 Community Relations

2.1.2.1 Introduction--

Community relations are an important aspect of all Superfund projects. It was especially important for the Commencement Bay project, where local authorities, citizen groups, and the community-at-large expressed an intense interest in the project. WDOE implemented and expanded the community relations task in the U.S. EPA/WDOE Cooperative Agreement.

The Tacoma-Pierce County Health Department (TPCHD), by interagency agreement with WDOE, was delegated to lead local implemention of the community relations program beginning in April, 1983. In response to input at a public meeting, the TPCHD formulated a Citizens Advisory Committee (CAC) to help implement the plan. Members of the CAC and their affiliations are listed in Table 3. In addition to the CAC and the general public, other interested groups included elected officials, the Port of Tacoma, the city of Tacoma, local industries, and the Puyallup Nation. Representatives from the Puyallup Nation, the Port of Tacoma, and the city of Tacoma also served on the TOC and regularly attended TOC meetings. The TOC also included representatives from involved federal, state, and local agencies. Environmental groups, businesses, and local residents were kept informed through their representatives on the CAC, the news media, press releases, and project update mailings. Citizens with questions about reported stories usually contacted the local health department or WDOE for clarification. Project libraries were also open to the public at TPCHD and WDOE.

A key goal in the initial community relations planning was the assurance that all concerned parties were accurately informed about the ongoing progress and findings, and that they had opportunities to provide inputs concerning the remedial investigation.

TABLE 2. TECHNICAL OVERSIGHT COMMITTEE MEMBERS AND AFFILIATION

Member	Affiliation
John Armstrong	U.S. EPA, Region X
Dick Bauer	U.S. EPA, Region X
Clifford Bosley	U.S. Fish and Wildlife Service
Dick Cunningham	WDOE, Southwest Regional Office
Curtis Dahlgren	Washington Department of Fisheries
Tom Deming	Puyallup Tribe
Jim Ebbert	U.S. Geological Survey
David Jamison	Washington Department of Natural Resources
Bob Kievit	U.S. EPA, Washington Operations Office
Jim Krull	WDOE, Chairman
Gary Kucinski	Port of Tacoma
Ed Long	National Oceanic and Atmospheric Administration
Steve Martin	U.S. Army Corps of Engineers, Seattle District
Merley McCall	WDOE, Southwest Regional Office
Frank Monahan	WDOE, Southwest Regional Office
Dan Petke	U.S. EPA/WDOE Northwest Regional Office
Doug Pierce	Tacoma-Pierce County Health Department
Rick Pierce	WDOE, Southwest Regional Office
Michael Price	City of Tacoma, Department of Public Works
Derek Sandison	Tacoma-Pierce County Health Department
Roger Stanley	WDOE, Industrial Section
David Stout	U.S. Fish and Wildlife Service
John Underwood	U.S. EPA, Region X
Bill Yake	WDOE, Water Quality Investigations Section

TABLE 3. CITIZENS ADVISORY COMMITTEE, COMMENCEMENT BAY NEARSHORE/TIDEFLATS REMEDIAL INVESTIGATION

Citizen	Affiliation
Nona Adams	League of Women Voters
Walt Adams	Tahoma Audubon Society
Peter Ariessohn	Pierce County Citizen
Mike Bradley	Vashon Island Citizen
Donald M. Carmichael	University of Puget Sound Law School
Mike Cooney	Tacoma Citizen
Mike Elenko	Tacoma Community House (Asian-American)
Dr. Biff Fouke	Pierce County Medical Society
Robert Gordon	Tahomans for a Healthy Environment
Douglas Jackman	Pierce County Medical Society
Frank Jackson	Vashon Island Community Council
Diane Robbins	Citizen
Beth Preslar	Citizen
Gary Preston	Epidemiologist, Vashon Island Citizen
Linda Tanz	League of Women Voters
Sheri Tonn, Ph.D.	Sierra Club
Rich McCurdy	City Club of Tacoma
To be named	Tacoma-Pierce County Chamber of Commerce
Agency/Consultant Representative	
Debbie Flood	U.S. EPA Region X
Bob Kievit	U.S. EPA Region X/WOO
James Krull	WDOE
Larry Marx	Tetra Tech, Inc.
Doug Pierce	Tacoma-Pierce County Health Department

Specific community concerns included:

- Potential health problems caused by consumption of contaminated fish and shellfish
- Potential impacts on recreational fisheries
- Communication of potential dangers to residents with language or cultural differences
- The effects of Commencement Bay contamination on local environmental quality and recreational values.

2.1.2.2 Objectives--

The general objective of the community relations program was to ensure that information was exchanged between the government agencies and consultants trying to understand and solve the nearshore/tideflats contamination problems and members of the community who are either affected by the problem or have information and perspectives that will help the agencies reach solutions. Through this information exchange, the public and local government agencies had ample opportunity to keep up with the project status and to review and contribute to project direction and findings.

Specific objectives included:

- Briefing the Tacoma-Pierce County Board of Health, Tacoma City Council, and other local officials on project status and progress
- Holding public meetings and distributing periodic project update sheets to inform local citizens about project status and direction in an understandable manner
- Utilizing the CAC to disseminate information to representative groups and for review of project presentations and documents
- Holding meetings as requested with interested citizens and groups to discuss findings, alternative remedies, and concerns
- Holding site tours by boat and bus to give visual perspectives and to disseminate site-specific information
- Using the Tacoma-Pierce County Health Department library and WDOE project office as central depositories of technical studies and other information concerning the nearshore/tideflats area
- Making results of the remedial investigation available through public workshops and documents at local public libraries, and at TPCHD, WDOE, U.S. EPA Region X, and Tetra Tech.

2.1.2.3 Implementation--

Several techniques were used during the remedial investigation to satisfy the objectives of the community relations program. Forming the Citizens Advisory Committee (CAC) was a major factor in implementing the program. Committee members represented professions and civic groups listed in Table 3. The CAC members viewed their roles and activities as educational, political, and critical, and felt that the community relations program should educate the public and elected officials on the complexities of the Superfund program and the remedial investigation. They also felt it was important to track reactions to Superfund activities.

Different techniques and activities used to meet the objectives of the community relations program are listed below:

Routine Activities

1. Meetings:
    - Citizens Advisory Committee
    - Tacoma-Pierce County Board of Health
2. Press releases
3. Periodic updates - mailed to local community, state, and local agencies and concerned citizens.

Special Activities

1. Presentations to special groups:
    - Local schools
    - Tacoma Community College
    - League of Women Voters
    - Tacoma City Club
    - Tacoma City Council
    - Tacoma Chamber of Commerce
    - Seattle City Club
    - Pierce Subregional Council of Puget Sound Council of Governments
    - Water Resources Council
2. Special flier to the Asian community concerning fishing and public health concerns
3. Industrial forum meeting (all industries within study area invited)
4. Local radio talk show
5. Bus tours of site:
    - Press/media
    - Puget Sound Water Quality Authority
    - Tacoma Community College

6. Boat tour of site:
   - Press
   - Tacoma City Club
   - Citizens Advisory Committee
   - Water Resources Council

7. Public Meetings.

It is planned that findings of the remedial investigation will be presented through the following activities:

Presentations/meetings:

- Citizens Advisory Committee
- Public meeting
- Governmental agencies (federal, state, and local)
- Press/media
- Local schools and colleges
- Documents made available at local libraries
- Chamber of Commerce - business/industrial community.

Because the level of concern remains high, community relations support will be maintained during both presentation of findings and execution of the remedial action feasibility study, if it is funded.

2.2 TECHNICAL AND SCIENTIFIC

2.2.1 Decision-Making Approach

The decision-making approach developed for the Commencement Bay Nearshore/Tideflats Investigation is described in detail in Tetra Tech (1984a) and is summarized below. Major elements of the Commencement Bay decision-making approach are presented in Figure 4.

The first step in the process was to determine the types of information needed to best meet the objectives of the project (i.e., the determination of problem areas, problem chemicals, problem sources, and a means of ranking these in priority order). Because cause-effect information did not exist for relating contaminant concentrations in the sediments to actual effects in the marine environment, it was necessary to collect information on both chemistry and biological effects. The indicators chosen were chemical contamination in the sediments, sediment toxicity as determined by laboratory tests of field-collected sediments (i.e., amphipod bioassays as a lethal indicator and oyster larvae bioassays as a sublethal indicator), bioaccumulation of contaminants in English sole and cancrid crabs, and biological effects (i.e., alterations of benthic invertebrate assemblages and liver lesions in English sole). Other ancillary kinds of information determined necessary were the physical characteristics of the sediments (i.e., grain size), the organic content of the sediments, and a measure of the oxidation state of the sediments. Chemical analysis of water column particulates was also determined to be useful in making judgments on contaminant movement in the project area.

The next step in the process was to review and evaluate the existing database. A sampling and analysis plan was then developed. Stations were

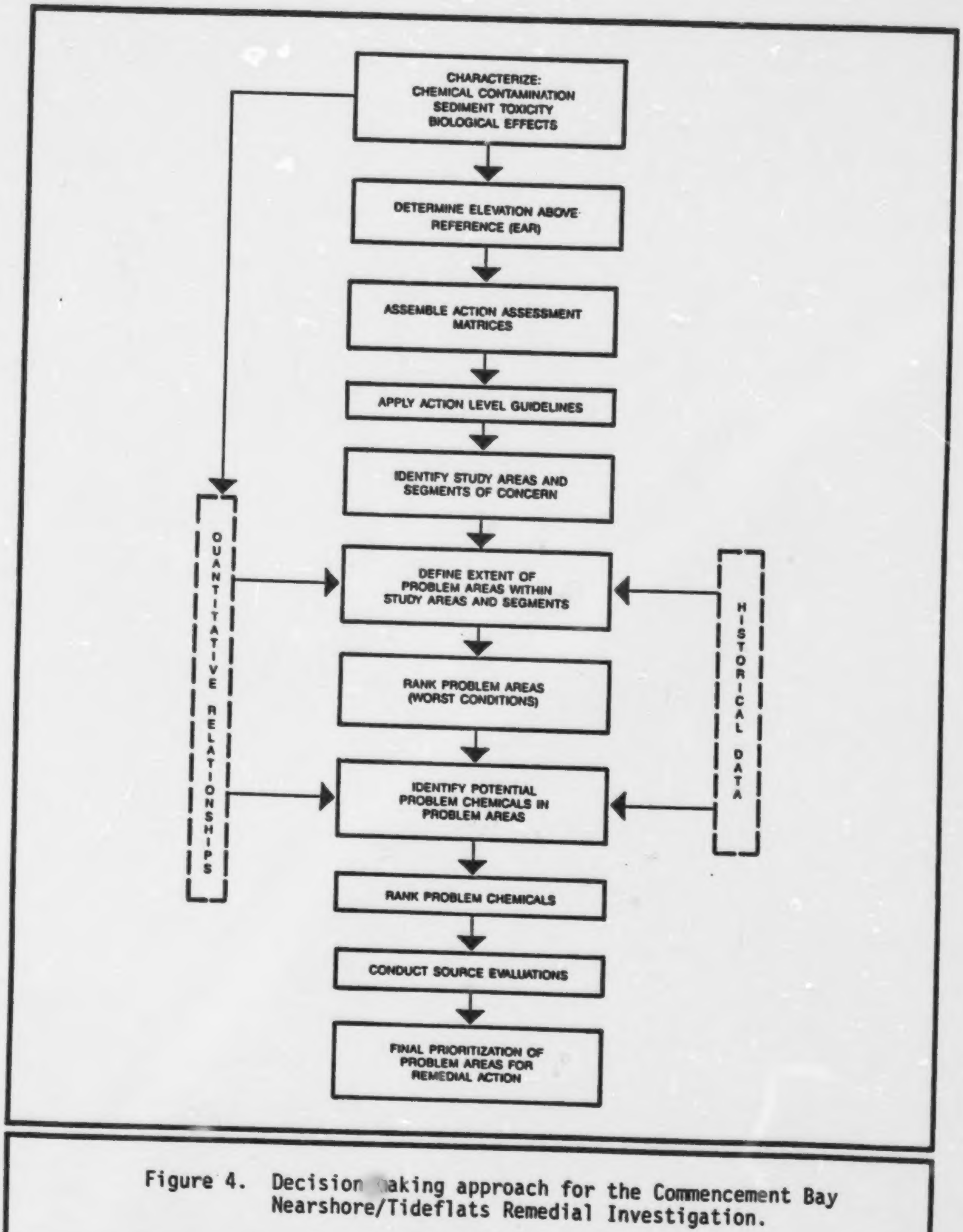
CHARACTERIZE:
CHEMICAL CONTAMINATION
SEDIMENT TOXICITY
BIOLOGICAL EFFECTS
DETERMINE ELEVATION ABOVE REFERENCE (EAR)
ASSEMBLE ACTION ASSESSMENT MATRICES
APPLY ACTION LEVEL GUIDELINES
IDENTIFY STUDY AREAS AND SEGMENTS OF CONCERN
QUANTITATIVE RELATIONSHIPS
DEFINE EXTENT OF PROBLEM AREAS WITHIN STUDY AREAS AND SEGMENTS
HISTORICAL DATA
RANK PROBLEM AREAS (WORST CONDITIONS)
IDENTIFY POTENTIAL PROBLEM CHEMICALS IN PROBLEM AREAS
RANK PROBLEM CHEMICALS
CONDUCT SOURCE EVALUATIONS
FINAL PRIORITIZATION OF PROBLEM AREAS FOR REMEDIAL ACTION

Figure 4. Decision making approach for the Commencement Bay Nearshore/Tideflats Remedial Investigation.

located to fill gaps in the historical database, to define more precisely areas of known contamination, and to evaluate gradients of contamination and effects relative to suspected sources of contamination.

A reference area (Carr Inlet) was selected so that Commencement Bay data could be compared with data from an embayment judged to have relatively uncontaminated sediments. Carr Inlet is located away from the industrialized areas of Puget Sound. Concentrations of chemicals in the sediments sampled from Carr Inlet were comparable or lower than those in other Puget Sound reference areas.

The sampling plan was implemented by an intensive field survey conducted from January to August, 1984 (summarized in Section 2.2.4). Results of the field survey were used to characterize the project area on several degrees of spatial resolution:

- Overall Project Area
- Study Areas (the eight waterways and the Ruston-Pt. Defiance Shoreline)
- Segments (the larger study areas were divided into segments)
- Problem Areas (areas within segments determined to be a problem).

Characterization with respect to degree of sediment contamination, toxicity, bioaccumulation, and biological effects was achieved by establishing an index for each environmental variable or indicator investigated, calculating "elevations above reference" (EAR) for each indicator, and testing each EAR for significance. For toxicity, bioaccumulation, and biological effects, a significant EAR was one that was statistically different ($P<0.05$) from Carr Inlet (except for benthic alterations within the waterways, where Blair Waterway was used in lieu of Carr Inlet). For sediment chemistry the EAR (elevation above reference in Carr Inlet) was determined to be significant if the contaminant value exceeded the maximum value in any of several reference areas throughout Puget Sound. The Puget Sound reference areas used are named in Volume 1, page 3.34 for organic compounds, and in Volume 1, page 3.18 for metals.

In addition to characterization of the project area as described above, results of the field survey were also used to develop quantitative relationships among sediment contamination, toxicity, and biological effects. These analyses were conducted primarily to determine levels of sediment contamination above which significant toxicity or biological effects would be expected to occur, and to identify contaminants suspected of causing the observed effects. Results of the quantitative relationships analyses were used to help define boundaries of problem areas and to identify potential problem chemicals.

EAR for study areas and segments were assembled into action assessment matrices. These matrices display the indices (EAR) for each environmental variable or indicator for each study area or segment under consideration. Also displayed is whether the EAR is significant or not significant and the reference value from which the EAR was determined. An example of an Action Assessment Matrix is shown in Table 7, Section 3.3. Action-level guidelines were then applied to the matrices to identify study areas and segments of concern. Each study area or segment of concern included either a problem area that extended over most of the study area or segment, or a "hot spot" of major significance within the study area or segment. The action-level guidelines defined the minimum levels and specific combinations of environmental indicators required before problem area definition could proceed. This threshold for action was always exceeded if at least three of the five indicators of sediment contamination, toxicity, and biological effects were determined to be significantly elevated above reference conditions in an area. More stringent requirements were applied if less than three indicators were significantly elevated in an area.

After areas of concern were defined, problem areas were identified and their spatial extents were determined. Problem area definition incorporated all available data, including historical data and use of results of the quantitative relationships among indicators developed as part of the present study. Problem areas were then ranked according to their most extreme levels of contamination, toxicity, and biological effects. Priority for evaluation of potential sources of contamination was based on this ranking. Potential problem chemicals were also identified and ranked at this point.

After problem areas and potential problem chemicals were identified and ranked, potential sources of contamination were evaluated. Final prioritization of problem areas recommended for remedial action was then determined on the basis of the relative magnitude of problems in each area, the spatial extent of each area, and the level of confidence that sources of potential problem chemicals were accurately identified.

2.2.2 Data Management

The data management system developed for the Commencement Bay project consisted of a central database, additional data analysis packages, and a library. The system was developed using an IBM microcomputer and the Knowledge Manager relational database software package published by Micro Data Base Systems, Inc.

The Commencement Bay database consists of 23 data files, each storing a different kind of data. Data of different kinds are linked together by common identifiers (e.g., survey, station, drainage). At present, the database contains over 25,000 records, each consisting of 15-150 separate variables. There are descriptions of over 50 surveys, 500 sampling stations, and 2,000 samples of water, solids, and biota. Over 400 components of the Commencement Bay drainage system have been identified. Included are data on sediment and water column chemistry, bioassays, benthic invertebrates, fish pathology, and bioaccumulation. All data were subjected to rigorous quality assurance procedures before entering the database.

Within the data management system, data are manipulated using a menu-driven system, which allows access to all files. Data retrieved by the menu-driven system can be written to a file and then included in word-processed reports, used with various data analysis programs, or transferred to other computers via modem. For the Commencement Bay projects, extensive use was made of spreadsheets (particularly LOTUS 1-2-3 published by Lotus Development Corporation) and SPSS statistical software (published by SPSS, Inc.).

A project library was developed to hold over 500 documents (e.g., reports, correspondence, and maps) relevant to the Commencement Bay project. Each document is filed under an accession number. This information is linked to the database to facilitate retrieval of original sources of information. A complete copy of the library is located at the WDOE project office in Olympia and at Tetra Tech, Inc. in Bellevue.

2.2.3 Data Review and Evaluation

One of the first components of the Commencement Bay Superfund project was a detailed review and evaluation of all historical data relevant to the project area. Information was compiled from the WDOE library, the U.S. EPA Region X library, the University of Washington library system, the Tetra Tech library, WDOE files (Headquarters and Southwest Regional Office), Port of Tacoma files, files of the Tacoma-Pierce County Health Department, files of the Puget Sound Air Pollution Control Agency, and personal contacts with scientific investigators (WDOE, COE, EPA, NOAA, UW).

A detailed description of the data review and evaluation process is presented in Tetra Tech (1983). Briefly, data were evaluated according to the following criteria:

- Type of data (e.g., sources, contamination, environmental effects)
- Location(s) and time(s) of sampling
- Sampling methods (e.g., collection, handling, storage, and replication)
- Analytical methods (e.g., accuracy, precision, and detection limits)
- Quality assurance/quality control procedures (e.g., spikes, blanks).

Data considered unacceptable for the needs of the Commencement Bay project were not considered beyond the evaluation step. Acceptable data were summarized in a matrix format and entered into the Commencement Bay database. In addition, station locations for all acceptable data were plotted on maps of project study areas.

The acceptable data screened by the review and evaluation process were used to 1) identify known sources of contamination, 2) identify known areas of contamination and effects, and 3) identify data gaps in the historical database. This information was then used to help design the preliminary and main field studies.

2.2.4 Field Sampling Design

Field studies for the Commencement Bay Nearshore/Tideflats Remedial Investigation were designed to determine the degree and spatial extent of chemical contamination, adverse biological effects, and potential threats to public health. This information was used in conjunction with historical data to formulate decision criteria which, in turn, were used to identify problem areas and to prioritize these areas for possible source control and/or sediment remedial action (Section 2.2.1). This decision-making approach is described in detail in Tetra Tech (1984a).

The general sampling design for the Commencement Bay project is presented in Table 4. Chemical contamination was measured in three media: bottom sediments (surface and subsurface), water column particulates, and animal tissues. Four kinds of biological effects of chemical contamination were also measured: alteration of benthic macroinvertebrate assemblages, toxicity of sediments to bioassay organisms (amphipods and oyster larvae), prevalence of histopathological disorders in English sole livers, and bioaccumulation (English sole and cancrid crab muscle tissue). In addition to the data collected as part of the main Commencement Bay project, contaminant and effects information was collected in Blair Waterway as part of the Blair Waterway Dredging Survey, a combined effort between the Port of Tacoma and the Commencement Bay Superfund project. Because these samples were collected using methods identical to those of the Commencement Bay project, the resulting data were included in the analyses in the present report.

Final selection of sampling stations was based on historical data and on the results of a preliminary survey conducted in January, 1984. Stations were selected to fill data gaps, to define more precisely known areas of contamination, and to determine gradients of contamination in relation to suspected sources.

The extent and magnitude of chemical contamination of sediments was determined by comparing chemical concentrations in Commencement Bay study areas with reference conditions in Carr Inlet. Known and blind replicate samples prepared from homogenized sediments were analyzed as part of the quality assurance program to establish precision of laboratory methods. Within-station variability was not evaluated. Therefore, tests for statistically significant differences between Commencement Bay and Carr Inlet that use within-station variability were not conducted. Sediment contamination was defined instead as "significant" if the concentrations in Commencement Bay sediments exceeded all reported values (or detection limits) in any of nine Puget Sound reference areas, including Carr Inlet.

Pearson linear correlation analyses and factor analyses were performed for subsets of chemical data. Results were used to establish relationships among the distributions of chemicals in Commencement Bay study areas, and among sediment contamination, sediment toxicity, and benthic infaunal abundances. "Apparent effect thresholds" (AET) for different chemicals were established by comparing the range of concentrations for each chemical in each of two groups of stations: 1) stations where no significant toxicity or depression in benthic infaunal abundances was observed, and 2) stations where some toxic or benthic effect was observed. The toxicity AET is the concentration of a chemical above which significant sediment toxicity would

TABLE 4. SUMMARY OF GENERAL STUDY DESIGN

Variable	Number of Stations Commencement Bay	Carr Inlet	Study Areas[a] Sampled	Time of Sampling[b]
Sediment Chemistry				
Surface	15	4[c]	HY,BL,MI,MD,CI,RS,CR	January
	111	4	All	March
	12		BL	July
Subsurface	18		HY,SI,SP,MD,CI,RS	May
	17		BL	July
Water Column Chemistry	9		HY,BL,SI,MI,MD,CI	April August
Benthic Macroinvertebrates	44	4	All	March
	6		BL	July
Sediment Bioassays	46	4	All	March
	6		BL	July
Fish Histopathology	15	2	All	June
Bioaccumulation	15	2	All	June

[a] The nine study areas include Hylebos (HY), Blair (BL), Sitcum (SI), Milwaukee (MI), St. Paul (SP), Middle (MD) and City (CI) Waterways, the Ruston-Pt. Defiance Shoreline (RS), and Carr Inlet (CR).

[b] All sampling was conducted in 1984. The stations sampled in January were part of the preliminary survey and the stations sampled in July were part of the Blair Waterway Dredging Survey.

[c] At two of these stations, only conventional sediment variables were measured.

always be expected. Similarly, the benthic effects AET is the concentration of a chemical above which significant benthic effects would always be expected. The toxicity AET and the benthic effects AET may or may not occur at the same concentration of a chemical.

To determine the potential biological effects of the observed chemical contamination, each of four biological indicators (i.e., benthic macroinvertebrates, sediment bioassays, fish histopathology, and bioaccumulation) were compared between Commencement Bay and Carr Inlet. Although some comparisons were qualitative (i.e., descriptive), most were based on statistical criteria. Use of such criteria ensured that impacts were judged objectively. If possible, comparisons were made using parametric statistical methods. Where the assumption of parametric tests could not be met using either untransformed or transformed (e.g., logarithmic) data, nonparametric methods were used with untransformed data.

2.2.5 Source Investigations

The main objective of the source investigations was to identify and prioritize the major sources of contaminants in Commencement Bay sediments. Because of the complexity of the study area, the numerous contaminants present, and the extensive industrial development of the area, the conduct of source identifications represented a complex assessment requiring evaluation of many data types.

The Water Quality Investigations section of the Washington State Department of Ecology (WDOE) was given responsibility for five projects to be completed under Task 4 (Determine Sources of Contamination and Characterize as a Current or Historical Source) of the Commencement Bay Nearshore/Tideflats Remedial Investigation. The five projects included:

- Assessment of log sorting yards as metals sources to the Commencement Bay waterways
- Metals in Hylebos Creek drainage as a metals source to Hylebos Waterway
- Routine monitoring of major point sources (other than NPDES) to Commencement Bay waterways
- Source identification of metals in Sitcum Waterway sediments
- Sources of metals and organic priority pollutants to City Waterway sediments.

The Tacoma-Pierce County Health Department conducted an investigation to identify all drains, seeps, and channels that discharge into the waterways and bay in the tideflats area; to identify the drainage network into the Fife area (Hylebos Creek and Wapato Creek); and to identify outfalls and drainage systems along the Ruston Way shoreline. The investigation was comprehensive, incorporating information gathered from the numerous case studies and identifications previously performed in the area. It provided a permanent record of outfall locations and drainage systems in place at the time of the study. Chemical analysis was performed on effluents from selected outfalls and points within the drainage systems to determine whether pollutants were entering the aquatic ecosystem and to identify significant sources of pollution not already recognized through previous case studies. Extensive shoreline investigations were performed at low tide by boat and on foot. Contributing drainage systems were evaluated by walking along open channel systems, surveying, some dye testing, and verification of manhole and catch basin locations for closed storm systems on record. Maps and records of the storm systems for the political entities in the area were obtained and verified.

The efforts of source identification integrated a large database on potential contaminant sources, observed contaminant levels in water and sediment, and ancillary information. Some of the most valuable information utilized in source identification included:

- Spatial gradients of contamination in surficial sediments
- Vertical gradients of contamination in sediment cores
- Analyses for the contaminant(s) in discharges
- Dredging history
- Environmental fate processes
- Industrial activities.

Evaluation of spatial gradients of contamination in surficial sediments was the most important component of the source identification process. Spatial gradients were evaluated both on a one-dimensional (along the length of the waterway) and on a two-dimensional basis. These evaluations were conducted using contaminant concentrations expressed as a dry weight concentration in sediment. Organic contaminant concentrations normalized to organic carbon were also used to aid in determination of spatial gradients. Evaluation of spatial gradients was used to establish the probable location of contaminant sources, with the implicit assumption that the most contaminated sediments were in closest proximity to the sources.

Evaluation of vertical gradients of contamination in sediment cores was used to assess the historical pattern of contaminant input. For example, greatest contaminant concentrations in the uppermost sediments indicated ongoing or recent input or past input exposed by dredging, ship scour, etc. Alternatively, subsurface contaminant maxima suggested that greatest inputs occurred in the past, or that the area had been covered recently by clean material. Uniform contaminant concentrations with depth suggested long-term input, groundwater contamination, or interstitial water mobility of the contaminant.

The contribution of contaminants by point sources and runoff was assessed by use of loading estimates (the quantity of material expressed in lb/day released to the water). These loading estimates were calculated from all available measurements of discharge flow rates and contaminant concentrations in the Commencement Bay database. The majority of discharge flow and concentration measurements in the database came from WDOE investigations (e.g., Class II surveys) and Commencement Bay nearshore/tideflats remedial surveys conducted by U.S. EPA, Tacoma-Pierce County Health Department, and specific industries. For each contaminant of concern, an average loading was calculated for each discharge into the defined problem area for which flow and concentration data were available.

There is evidence of groundwater contamination within many portions of the nearshore/tideflats area because of past spills, use of unlined industrial waste ponds, and landfilling of hazardous materials. Local, state, and federal agencies were contacted to obtain all available data for information on groundwater flow and contamination. These agencies included the Port of Tacoma, Tacoma Public Utilities Department, Pierce County Department of Public Works, State Department of Highways, WDOE, and the U.S. Geological Survey. The existing data were very limited. In general, existing data were inadequate to determine the magnitude of groundwater contamination, to predict the route of groundwater flow from a contaminated area, and to determine the loading of contaminants to the waterways via groundwater.

Files of both the U.S. Coast Guard (USCG) and WDOE were reviewed to obtain information on past spills of hazardous materials in the nearshore/tideflats area. The USCG files were not useful because spill locations were imprecise (i.e., reported only to the nearest minute latitude and longitude) and little information on chemical constituents of spilled material exists. For example, a spill at 47° 16' N latitude and 122° 26' W longitude could have occurred in the Puyallup River; St. Paul, Middle, or City Waterways; or southeast Commencement Bay. WDOE files for 1979 to 1985 contained reports of approximately 30 hazardous material spills with potential effects on water quality in the study area. About 35 petroleum spills in excess of 50 gallons were also documented during the same period.

The dredging history of the nearshore/tideflats area was reviewed to help interpret horizontal and vertical contamination gradients observed in the sediment core samples. Information on maintenance dredging activities and private dredging activities within the nearshore/tideflats area was obtained by a WDOE review of U.S. Army Corps of Engineers (COE) and U.S. EPA files. All dredge and fill applications submitted to the COE from 1972 to the present were reviewed to identify the industrial applicant, the spatial extent of dredging activities, and the volume of material intended for removal.

2.2.6 Endangerment Assessment

The objective of the endangerment assessment for the Commencement Bay Investigation was to evaluate public health risks associated with consumption of contaminated seafood from the study area. This assessment considered three routes of contaminant exposure: consumption of fish muscle tissue, crab muscle tissue, and fish livers. The overall assessment consisted of an exposure evaluation and a prediction of health effects (i.e., risks).

The first step in the exposure assessment was to calculate the exposed population (i.e., individuals consuming fish or shellfish from Commencement Bay). Estimates of the exposed population were obtained from a survey conducted by the Tacoma-Pierce County Health Department (TPCHD, Pierce et al. 1981). Based on results of that survey, 4,070 shore and boat anglers were estimated for Commencement Bay. The average family size was 3.74 persons, resulting in a predicted exposed population of 15,200 persons.

The second step in the exposure evaluation was to calculate the amount of fish consumed by the exposed population. This was accomplished by using the information provided in the Tacoma-Pierce County Health Department's Catch Consumption Survey to estimate the frequency of fishing and multiplying that value by the average catch per trip of nonsalmonid fishes intended for consumption. These calculations indicated that a small proportion of the exposed population (i.e., 30 of 15,220 or 0.2 percent) consumed fish at the highest estimated rate of 1 lb/day. These calculations also indicated that 82 percent of the exposed population consumed less than 1 lb/month and that over half the population (57 percent) consumed Commencement Bay fish at the lowest rate of 1 lb/year. No data were available on shellfish consumption rates. Consumption of crabs was therefore assumed to follow a distribution equal to fish consumption.

The final step in the exposure evaluation was to multiply the estimated seafood consumption rates by the concentrations of contaminants in fish and crab tissue. Tissue contaminant data collected as part of the present study were used for this analysis.

No data were available on consumption rates of fish livers. Therefore, it was assumed that all persons who eat fish livers eat them from all the fish they catch. It was also assumed that the liver mass was proportional to the liver-to-muscle ratio (12 percent) of Commencement Bay fishes. Therefore, at the maximum estimated fish consumption rate of 1 lb/day, the corresponding maximum liver consumption rate would be 0.12 lb/day.

Exposure calculations were used to predict carcinogenic and noncarcinogenic risks to public health. Carcinogens in this assessment were substances that the U.S. EPA considers possible cancer-causing agents. Public health risks from ingestion of carcinogens was estimated using the U.S. EPA's Carcinogen Assessment Group methodology (U.S. EPA 1984). Estimated individual lifetime risks were calculated by multiplying the exposure for each of the contaminants by U.S. EPA's unit risk scores.

Noncarcinogens were assumed to have threshold toxic responses (i.e., to cause some ill effect only after a certain dose is exceeded). Therefore, calculated exposures for these substances were compared with published Acceptable Daily Intakes (ADIs). Effects were predicted in the exposed population if exposure exceeded the ADI.

2.2.7 Identification of Potential Remedial Technologies

The four major objectives in this part of the investigation were: 1) to describe and evaluate alternative dredging methods and equipment, disposal methods and sites, and site control and treatment practices for contaminated sediments; 2) to develop a preliminary decision-making framework for the management of dredged material; 3) to prioritize sources of problem chemicals within each problem area; and 4) to delineate the remedial technologies applicable to each hot spot or problem area.

The U.S. Army Corps of Engineers (COE) conducted an assessment of alternative dredging methods and equipment, disposal methods and sites, and site control and treatment practices for contaminated sediments derived from Commencement Bay. These alternatives were evaluated based on:

- Cost of each alternative
- Degree of confinement and release of volatile, soluble, and sediment-bound contaminants resulting with each alternative
- Considerations and limitations specific to each alternative (e.g., equipment and site availability, method efficiency, equipment depth limitations, sociopolitical concerns, and other indicators of practicability).

The COE also developed a decision-making framework for dredged material management. The decision-making framework is based on the results of technically sound test protocols, and considers sediment chemistry, the physicochemical nature of disposal site environments, and the biological effects of sediment contaminants. Test results from sediments to be dredged are compared with test results from reference sediments and with established criteria. Test protocols are discussed that consider the physicochemical conditions posed by open-water disposal environments and by confined nearshore and upland disposal environments. Descriptions of the physicochemical conditions at each disposal environment are provided as well as descriptions and citations of the test methods to be conducted. In addition, examples of test results obtained from recent test applications at other COE dredging projects are discussed. Test results are used to formulate management strategies for placing dredged material in specific physicochemical disposal environments and to determine treatment and control methods for disposing of contaminated sediments in an environmentally acceptable manner.

To define remedial technologies, two aspects of sediment contamination in Commencement Bay were considered: the type and magnitude of contaminated sediments, and the mechanisms by which contaminants enter the bay. Technologies were classified according to the problem they addressed. Management technologies for sediments were aimed at reducing or mitigating the environmental and public health threats associated with contaminated sediments. Control technologies for sources were aimed at reducing or preventing contaminants from entering the marine environment. Sediment management technologies were classified as removal or in situ methods, and source control methods were classified as point or nonpoint technologies. A list of all potential remedial technologies was generated, including a description of their applications, limitations, cost estimates, advantages, and disadvantages. Remedial technologies were not further screened or ranked, as these evaluations will be performed in the feasibility study.

Prioritization of sources for remedial action was based on the priority of the observed contaminants, degree of confidence in source identification, magnitude of relative loading (if known), and method of remedial action implementation. For each problem area where contamination sources were identified, a list of potential remedial technologies was developed for those sources. Additional source identification methods were recommended for those contaminants with unknown and potential sources.

2.2.8 Quality Assurance/Quality Control (QA/QC)

QA/QC procedures for the Commencement Bay Nearshore/Tideflats Superfund Investigation were applied to cover interdisciplinary field sampling, laboratory analyses, data validation, and data analysis. These procedures covered collection and analysis of water, fishes, crabs, surface sediments, subsurface sediments, and suspended particulate material. Field samples were analyzed for organic and inorganic chemistry, benthic ecology, sediment toxicology, and fish pathology. Field tasks were integrated by establishing common sampling sites, sampling methods, and sampling times for related disciplines, as specified in the project sampling and analysis plan (Tetra Tech 1984b). Specific procedures used in each area are summarized in a QA/QC plan approved by the U.S. EPA and WDOE (Brown and Caldwell and E.V.S. Consultants 1984).

In addition, for chemical analyses, a method validation study was conducted to evaluate chemical protocols used for the determination of trace organic compounds in sediments by four analytical laboratories. Results from analytical laboratories were reviewed by Tetra Tech for conformance with QA/QC requirements. Detection limits, accuracy, precision, completeness, and conformance with the specified protocol were verified during data review. Ten to twenty percent of the data was examined in a complete verification effort. The remainder of the data was evaluated for outliers and completeness prior to database entry. All of the spectral data for the tentatively identified organic compounds were manually examined. When possible, QA audits included the use of known geochemical trends in environmental data to evaluate the reliability of the data returned for interpretation.

2.2.9 Health and Safety

Because soils, sediments, water, and waste material associated with contaminated areas may present significant health hazards, personnel who came into direct contact with contaminated materials were provided with personal, dermal, and respiratory protection.

Safety plan guidelines developed for the Commencement Bay Nearshore/Tideflats Remedial Investigation (Tetra Tech 1983) covered field procedures to collect and process samples of water, sediment, fishes, and crabs. These guidelines also covered other activities that might be associated with future Superfund activities (e.g., surveying, dredging, excavation and dewatering of sediment, and waste hauling).

The site-specific safety plan for the investigation (Brown and Caldwell and E.V.S. Consultants 1983) ensured safe conduct of field operations and collection of data. The plan specifically called for a modified Level D protection, with the substitution of marine rubber work boots with non-slip soles for steel-toed boots. Monitoring equipment included an HNu photoionization detector and personnel organic monitoring badges. Collection of certain deep core and sediment samples required the use of respirators with GMC-H combination cartridges for acids, gases, and organic vapors (MSA 464046).

The site safety plan guidelines and site-specific safety plan were approved by the WDOE Project Manager and the U.S. EPA Region X Safety Officer.

3. RESULTS

3.1 ENVIRONMENTAL CONCERNS

3.1.1 Contamination

The evaluation of contamination in Commencement Bay focused on surface and subsurface subtidal sediments. General objectives of the sediment contamination studies were to:

- Determine the magnitude of contamination relative to the project reference area (Carr Inlet)
- Develop a condensed list of chemicals of concern (i.e., concentrations exceeding maximum Puget Sound reference levels) from the numerous chemicals analyzed in Commencement Bay sediments
- Develop a list of Commencement Bay areas with highest levels of each chemical of concern.

Commencement Bay study areas were divided into 20 segments as shown in Figure 5. The major reason for defining segments was to provide a means of reporting major chemical, sediment toxicity, and biological gradients within areas that sometimes contained dozens of stations in various arrays. Hence, small areas such as Sitcum, Milwaukee, St. Paul, and Middle Waterways were not subdivided. Boundaries of segments within large areas were generally established to define major zones of varying chemical contamination. Contamination from one group of chemicals sometimes extended well past a segment boundary defined according to a zone of contamination for other chemicals.

At a minimum, each segment was required to contain at least three stations (except Segment CIS2 which consisted of the isolated Wheeler-Osgood branch of City Waterway). Segments were also required to contain at least one station for which complementary biological and sediment toxicity data were available (except Segment BLS4 located in deeper water outside of Blair Waterway). Average concentrations of chemicals within segments are used in later discussions to evaluate trends in chemical concentrations along areas. "Hotspots" of chemical contamination are evaluated at individual stations when chemical gradients are apparent within segments.

3.1.1.1 Metals--

3.1.1.1.1 Surface Chemistry--Metals were detected over a wide range of concentrations in Commencement Bay surface sediments (i.e., <1 to >30,000 mg/kg dry weight). Highest concentrations of most metals were measured along the Ruston-Pt. Defiance Shoreline near the ASARCO smelter. Comparisons with the range of Puget Sound reference levels indicated that concentrations of beryllium, chromium, and silver were not significantly elevated in Commencement Bay sediments. There was no evidence of elevated selenium or thallium

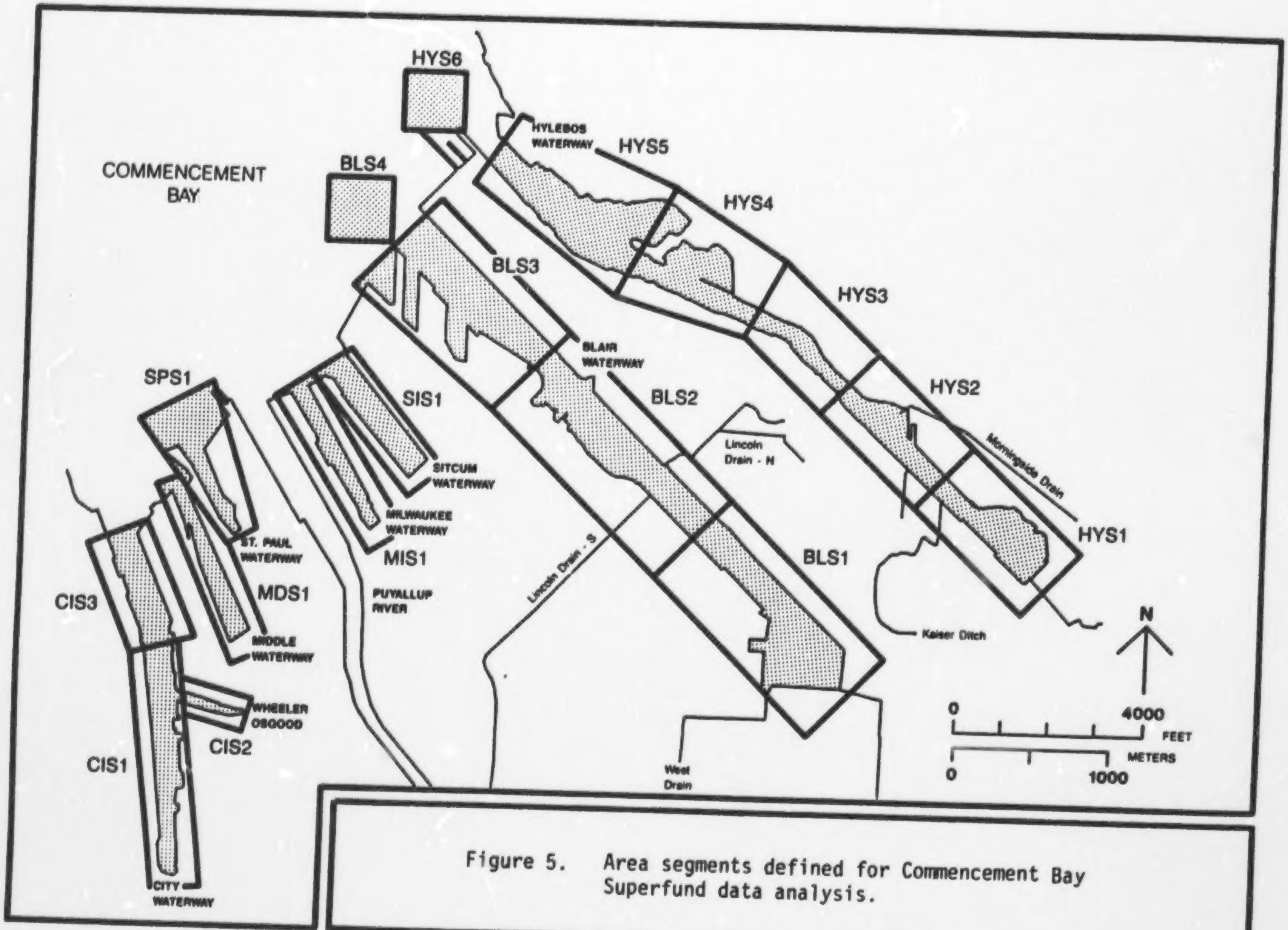
COMMENCEMENT BAY
HYS6
BLS4
HYLEBOS WATERWAY
HYS5
HYS4
HYS3
HYS2
HYS1
Morningside Drain
Kaiser Ditch
BLS3
BLAIR WATERWAY
BLS2
BLS1
Lincoln Drain - N
Lincoln Drain - S
West Drain
SIS1
SITCUM WATERWAY
MILWAUKEE WATERWAY
MIS1
PUYALLUP RIVER
SPS1
ST. PAUL WATERWAY
MDS1
MIDDLE WATERWAY
CIS3
WHEELER OSGOOD
CIS2
CIS1
CITY WATERWAY
N
0
4000
FEET
METERS
0
1000

Figure 5. Area segments defined for Commencement Bay Superfund data analysis.

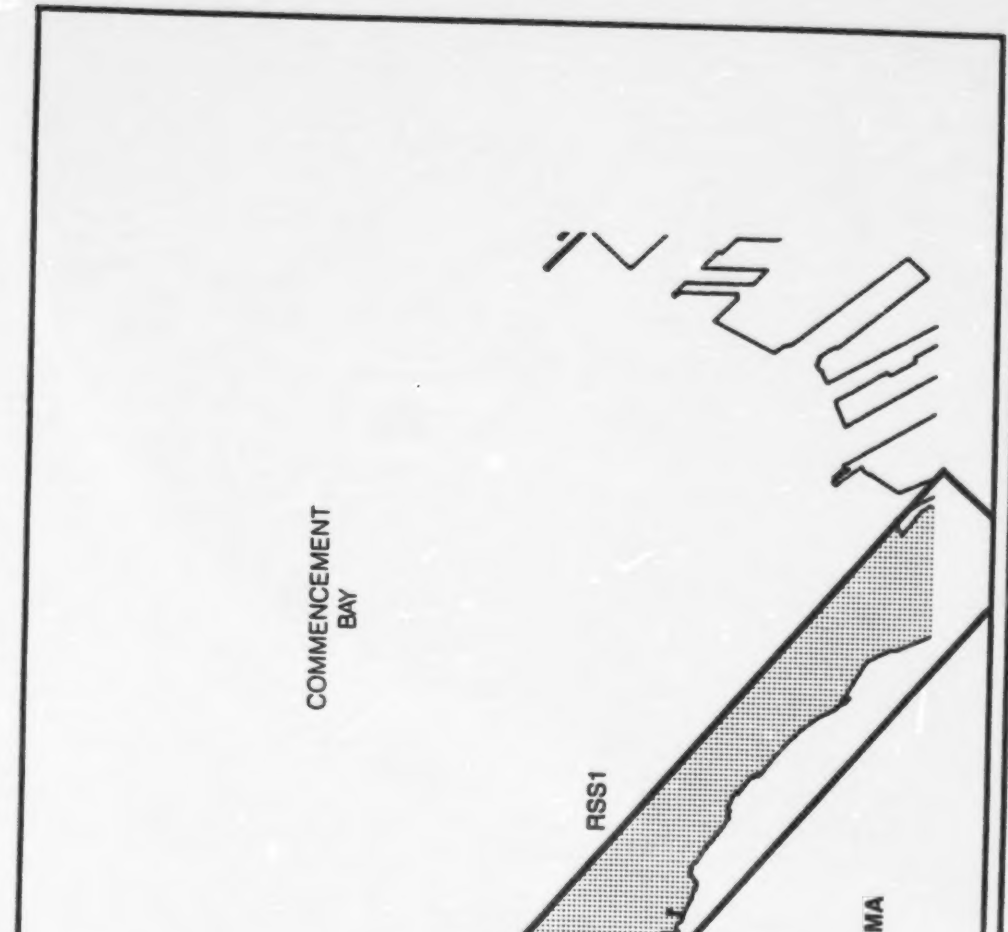
RSS3
RSS2
RSS1
COMMENCEMENT BAY
RUSTON
TACOMA
N
0
4000
FEET
0
1000
METERS

Figure 5. (Continued).

concentrations outside the Ruston-Pt. Defiance Shoreline area. The remaining eight metals (antimony, arsenic, cadmium, copper, lead, mercury, nickel, and zinc) were elevated above maximum Puget Sound reference levels at one or more sites in Commencement Bay, and were therefore identified as inorganic contaminants of concern.

For the Commencement Bay waterways, average elevations above Carr Inlet values (EAR) (by waterway) were typically less than a factor of 20 for sediment metals (i.e., metals concentrations in waterway sediments were less than 20 times those of Carr Inlet reference sediments). Individual sampling stations within the waterways had higher metals concentrations. The highest levels of metals contamination exceeded 1,000 times Carr Inlet levels for antimony and arsenic only at three stations near the ASARCO outfalls on the Ruston-Pt. Defiance Shoreline (Segment RSS2). Cadmium, copper, lead, mercury, and zinc were elevated above 100 times Carr Inlet concentrations in this area. Sediment metals concentrations decreased sharply both alongshore and offshore from the ASARCO plant vicinity. High metals concentrations also were observed in the Pt. Defiance area (Segment RSS3), and appeared to be associated directly with the presence of ASARCO slag.

Within the waterways, several localized areas of significant sediment contamination by metals were found. Upper Hylebos Waterway (Segments HYS1 and HYS2) was highly contaminated by metals, especially arsenic and copper. High concentrations of metals (including mercury) have also been reported in intertidal sediments from the south shore of Hylebos Waterway. Sitcum Waterway was distinguished from neighboring waterways by high EAR of most metals. Even higher metals concentrations were previously reported in nearshore sediments from Sitcum Waterway. The highest concentrations were found in the northeast corner of the waterway. Sediment concentrations of copper and mercury in Middle Waterway were among the highest observed in the waterways. Maximum levels were measured near the mouth of that waterway. City Waterway was distinguished by having some of the highest sediment lead concentrations found in the waterways. Lead concentrations decreased consistently from the head to the mouth of that waterway. Intertidal sediments along the eastern shoreline of City Waterway (south of Wheeler-Osgood) have high concentrations of copper, zinc, and, near the head of the waterway, nickel.

3.1.1.1.2 Subsurface Chemistry--Twenty-three sediment cores were collected in 13 areas of Commencement Bay containing contaminated surface sediments. The areas sampled were located in Hylebos, Sitcum, St. Paul, Middle, and City Waterways, and along the Ruston-Pt. Defiance Shoreline. Maximum subsurface concentrations of metals were observed in cores from the Ruston-Pt. Defiance Shoreline and were typically 1.5 to 3 times higher than maximum concentrations in surface sediments from the same area. Concentrations of priority pollutant metals (e.g., lead and copper) also did not vary substantially with depth in cores from Wheeler-Osgood Waterway, the middle of the main channel of City Waterway, and St. Paul Waterway. Concentrations of these metals in cores from other locations showed more variable patterns. Metals concentrations equal to Puget Sound reference conditions were found in the deepest interval of cores from Blair and Hylebos Waterway (except near the mouth of the waterway). Concentrations of metals in the deepest interval of cores from St. Paul Waterway and the head of City Waterway exceeded Puget Sound reference conditions by less than a factor of two. Concentrations of at least one metal in the bottom of cores from Sitcum, Middle, Wheeler-Osgood, and the mouths of City and Hylebos Waterways exceeded the range of Puget Sound reference conditions by more than a factor of two.

3.1.1.2 Organic Substances--

3.1.1.2.1 Surface Chemistry--Of the 133 U.S. EPA organic priority pollutants and hazardous substance list organic compounds analyzed in Commencement Bay sediments, 53 were undetected in surface sediments. For these compounds, analytical detection limits typically were in the low parts per billion range. Undetected compounds included 2,3,7,8-tetrachlorodibenzodioxin, and most organonitrogen compounds (bases), pesticides, and volatile compounds. Rarely detected organic substances included several substituted phenols and halogenated ethers. Of special note was the absence of pesticides such as aldrin, lindane, and DDT that were previously identified at relatively high concentrations in some areas of Commencement Bay. The highest historical pesticide values were found in subtidal and intertidal sediments from Hylebos Waterway. Intertidal sediments were not resampled in the current investigation.

Nineteen organic compounds or compound groups (representing 42 of the 133 organic priority pollutants and hazardous substance list organic compounds) were of concern because their concentrations in Commencement Bay sediments exceeded maximum concentrations in Puget Sound reference sediments. Six organic compounds were found at especially high concentrations (>1,000 times EAR) at individual stations: benzo(a)pyrene, 4-methylphenol, 2-methoxyphenol, phenanthrene, trichlorobutadienes, and tetrachlorobutadienes. Similarly high concentrations of hexachlorobenzene and hexachlorobutadiene were also reported in past studies of subtidal sediments from Hylebos Waterway. Additional compounds or compound groups with EAR from 100 to 1,000 at Commencement Bay stations included: low and high molecular weight aromatic hydrocarbons (LPAH and HPAH), dibenzofuran, 1,2-dichlorobenzene, bis(2-ethylhexyl) phthalate, PCBs, and 2-methylnaphthalene.

Hylebos Waterway displayed high sediment concentrations for several groups of organic compounds. Subtidal and intertidal sediments in that waterway contained the highest levels of chlorinated organic compounds (e.g., PCBs; chlorinated ethenes, benzenes, and butadienes; as well as a complex mixture of unidentified chlorinated compounds) in the project area. Highest levels of chlorinated butadienes and chlorinated benzenes occurred toward the waterway mouth. Chlorinated ethenes have been found in high concentrations in intertidal sediments in two areas along the south shore of Hylebos Waterway. The distribution of PCBs was patchy, with elevated levels occurring throughout subtidal sediments of the waterway. The entire upper reach of Hylebos Waterway was highly contaminated by HPAH. Blair, Sitcum, and Milwaukee Waterways generally had low concentrations of organic compounds compared with other areas of Commencement Bay. An area adjacent to the Champion International pulp mill near the mouth of St. Paul Waterway was characterized by organic contamination from methylated phenols and LPAH. Several parts of City Waterway were characterized by high levels of LPAH, HPAH, and chlorinated benzenes. High PCB concentrations reported at a single station near the mouth of City Waterway in an earlier study were not evident in the more recent sampling. Along the Ruston-Pt. Defiance Shoreline, the area adjacent to the ASARCO smelter was highly contaminated by several organic compounds, including PAH, PCBs, and 1,4-dichlorobenzene. With some of the exceptions noted, comparable or higher concentrations of most organic compounds were found in the current sampling of subtidal sediments as compared with past studies.

3.1.1.2.2 Subsurface Chemistry--Many organic compounds were measured at concentrations that were considerably higher in subsurface sediments than in surface sediments. Examples (with ratios of maximum subsurface to surface concentrations) include: 2-methylphenol (19), pyrene (22), 1,4-dichlorobenzene (41), hexachlorobutadiene (61), hexachlorobenzene (13). Highest concentrations of organic compounds were found in subsurface sediments from Hylebos and City Waterways. Concentrations of one major class of compounds, hydrocarbons, typically exceeded Puget Sound reference conditions by a factor of 2-10 at the bottom of all cores except those drilled in Blair Waterway. This was true even in the eight cores where the bottom intervals had no evidence of metals contamination.

3.1.2 Biological Effects

3.1.2.1 Benthic Macroinvertebrates--

Bottom-dwelling organisms are an integral part of marine and estuarine ecosystems. They consume organic materials, bioturbate sediments, promote nutrient regeneration from sediments, and are prey of fishes, birds, and marine mammals. Because benthic organisms are relatively sedentary, they cannot avoid organic materials and chemical contaminants deposited on the bottom. They are also sensitive to environmental disturbance, organic enrichment, and chemical contamination of the sediments. These characteristics make them an excellent indicator group for assessing the areal extents and magnitudes of environmental stresses.

In the present study, 119,095 benthic macroinvertebrates belonging to 407 species were collected at 56 stations. Total macroinvertebrate abundances at most stations in Commencement Bay ranged from 2,500 to 15,000/m^2. The most abundant taxonomic groups were Polychaeta (worms), Bivalvia (clams), Nematoda (worms), and Crustacea (e.g., amphipods). The polychaetes were represented primarily by Tharyx multifilis, and the bivalve molluscs were represented primarily by Axinopsida serricata. These two species accounted for 70,084 individuals, or 59 percent of all benthic organisms collected.

Among the nine study areas, numbers of species tended to be higher along the Ruston-Pt. Defiance Shoreline and in Carr Inlet than in the waterways. Conversely, total abundances tended to be higher within the waterways than along the Ruston-Pt. Defiance Shoreline or in Carr Inlet, because populations of some polychaete and mollusc species and populations of nematodes (at certain stations) were enhanced. The lower numbers of species, higher numbers of individuals, and enhanced abundances of a few species that typically occurred within the waterways resulted in communities dominated by a few species. Such "high dominance" communities are generally indicative of environmentally stressed areas, because less tolerant species are eliminated and opportunistic species tend to achieve higher abundances in stressed areas compared to unstressed areas.

The most adversely affected benthic assemblages in Commencement Bay were found off ASARCO, off Champion International, and at the head of City Waterway. The station closest to ASARCO (RS-18) was nearly devoid of benthic invertebrates. Of the four grab samples collected at this site, only two contained any macroinvertebrates (i.e., a total of seven organisms). The station closest to Champion International (SP-14) also was nearly abiotic, with only 32 organisms collected in four grab samples. This compares with an average of approximately 2,300 organisms collected in all four grab samples from each station within the Commencement Bay study area. The depressed abundances at Stations RS-18 and SP-14 indicate severe stress. Benthic invertebrate assemblages at stations off Champion International (SP-15) and at the head of City Waterway (CI-11) were numerically dominated (82.7 percent and 98.6 percent, respectively) by nematodes and by the polychaete *Capitella capitata*. Dominance by these taxa indicates organic enrichment of the sediments.

To develop indices of benthic effects, abundances of major benthic taxa (i.e., total taxa, Polychaeta, Mollusca, and Crustacea) at potentially impacted sites were compared statistically with their respective abundances at reference sites. A significant decrease ($P<0.05$) in the abundance of an indicator taxon was considered a benthic impact (i.e., a benthic depression). Because sediment grain size characteristics at the stations in Carr Inlet differed considerably from those at most waterway stations, Blair Waterway was used as a reference area for benthic determinations for the waterways. Blair Waterway was a relatively clean waterway with respect to sediment chemistry and toxicity. Carr Inlet was retained as the reference area for the Ruston-Pt. Defiance Shoreline and for Station HY-44 because sediment grain size characteristics were similar in these areas.

Results of the statistical comparisons (Figure 6) showed that no benthic depressions were found in Middle and Milwaukee Waterways. In Sitcum Waterway, single depressions (Crustacea) were found at two of three stations (SI-11 and SI-12). The remaining four study areas (Hylebos, St. Paul, and City Waterways, and the Ruston-Pt. Defiance Shoreline) included stations with multiple benthic depressions. Locations with multiple depressions included the head of Hylebos Waterway (HY-17, HY-22, and HY-23), the middle of Hylebos Waterway (HY-32), the stations closest to Champion International (SP-14 and SP-15), the head of City Waterway (CI-13), the Wheeler-Osgood branch of City Waterway (CI-16), and the station closest to ASARCO (RS-18).

Compared with the results of a study conducted in 1950 (Orlob et al. 1950), benthic conditions in the vicinity of Station RS-18 (near ASARCO) do not appear to have improved. Some improvement in benthic conditions does appear to have occurred in upper Hylebos and upper City Waterways, as these areas are no longer devoid of benthic macroinvertebrates, as the limited historical data indicate.

3.1.2.2 Fish Ecology--

English sole (*Parophrys vetulus*) was selected as the representative fish species for several reasons. First, this species is abundant and widespread throughout Commencement Bay, enhancing the probability that adequate sample sizes could be obtained at all study sites. Second, English

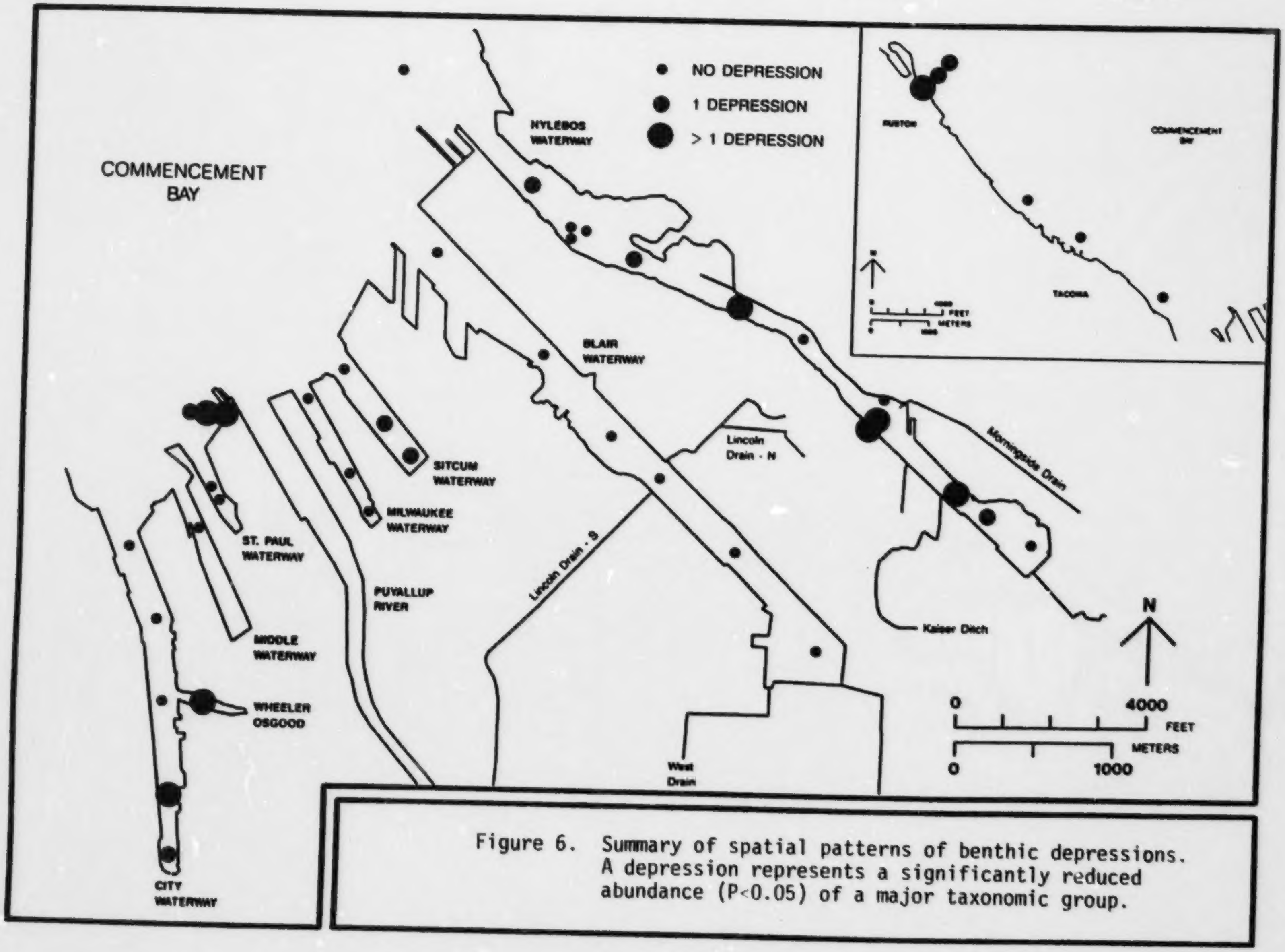
NO DEPRESSION
1 DEPRESSION
> 1 DEPRESSION
COMMENCEMENT BAY
HYLEBOS WATERWAY
BLAIR WATERWAY
SITCUM WATERWAY
MILWAUKEE WATERWAY
ST. PAUL WATERWAY
PUYALLUP RIVER
MIDDLE WATERWAY
WHEELER OSGOOD
CITY WATERWAY
Lincoln Drain - N
Lincoln Drain - S
West Drain
Morningside Drain
Kaiser Ditch
N
0
4000
FEET
METERS
0
1000
RUSTON
COMMENCEMENT BAY
TACOMA

Figure 6. Summary of spatial patterns of benthic depressions. A depression represents a significantly reduced abundance ($P<0.05$) of a major taxonomic group.

sole live in close contact with bottom sediments, prey mainly on small benthic infauna, and exhibit high levels of tissue contamination and disease in urbanized areas of Puget Sound (Malins et al. 1980, 1982). It is therefore likely that this species is being influenced by contamination of bottom sediments. Finally, because English sole is frequently caught and consumed by recreational fishermen, this speies is part of a pathway through which contaminants can move from sediments to humans.

General characteristics of the total bottom-dwelling fish assemblages and the English sole populations sampled at 17 trawl transects in Commencement Bay and Carr Inlet were examined qualitatively to determine if large differences existed between the two embayments. The total assemblages in Commencement Bay and Carr Inlet were compared with respect to species composition, number of species, species diversity, and total abundance. English sole populations in Commencement Bay and Carr Inlet were compared with respect to median length, abundance, and condition.

A total of 6,686 fishes, representing 17 families and 40 species, was collected in this study (Table 5). Commencement Bay study areas yielded 4,951 individuals and 38 species, whereas 1,735 fishes and 13 species were collected in Carr Inlet. Much of this discrepancy in species richness resulted primarily from the larger sampling effort expended in Commencement Bay (15 transects) compared to Carr Inlet (2 transects), but may also have been partly due to increased habitat complexity (e.g., pilings, rocks, debris) in Commencement Bay. The fish assemblages sampled in both Commencement Bay and Carr Inlet were dominated by pleuronectids (i.e., flatfishes). The most abundant pleuronectids were English sole (Parophrys vetulus) and rock sole (Lepidopsetta bilineata).

For six of the eight Commencement Bay study areas, total fish abundance (as catch per unit effort) was over twice as large as that in Carr Inlet. Only Hylebos Waterway and the Ruston-Pt. Defiance Shoreline had fish abundances similar to that in Carr Inlet. Total numbers of fish species in individual Commencement Bay study areas (e.g., waterways) were relatively similar to that in Carr Inlet. Diversity indices of fish assemblages in Commencement Bay study areas were greater than that in Carr Inlet. Diversity indices in four of the eight study areas (Hylebos, Milwaukee, and City Waterways, and the Ruston-Pt. Defiance Shoreline) exceeded that in Carr Inlet by a factor of 1.5 or more. These results indicate that the distribution of individuals among species is more even in Commencement Bay waterways than in Carr Inlet. In summary, fish assemblages in Commencement Bay study areas generally were more abundant and more diverse than those in Carr Inlet, whereas total numbers of species were similar among all areas. Although these comparisons are largely descriptive, they show no indication that the gross characteristics of fish assemblages in Commencement Bay were negatively affected by chemical contamination.

Although relative abundances of English sole were similar between the two embayments, length distributions of captured fish were significantly different ($P<0.001$). Median length of English sole in Carr Inlet (14.9 cm) was substantially lower than that in Commencement Bay (25.2 cm) because populations in the former embayment were dominated by young fish. This size discrepancy probably arises from the fact that juvenile English sole prefer shallow sandy habitats as nursery areas. Thus, the muddy nature

TABLE 5. RELATIVE ABUNDANCES OF FISHES CAPTURED IN COMMENCEMENT BAY AND CARR INLET

Family	Species	Common Name	Relative Abundance (%) Commencement Bay	Carr Inlet
Squalidae	*Squalus acanthias*	spiny dogfish	0.1	
Rajidae	*Raja rhina*	longnose skate		0.1
Chimaeridae	*Hydrolagus colliei*	spotted ratfish	2.3	
Clupeidae	*Clupea harengus pallasi*	Pacific herring	2.1	
Engraulidae	*Engraulis mordax mordax*	northern anchovy	a	
Batrachoididae	*Porichthys notatus*	plainfin midshipman	0.1	
Gadidae	*Gadus macrocephalus*	Pacific cod	a	
	Merluccius productus	Pacific hake	0.1	
	Microgadus proximus	Pacific tomcod	4.3	
Zoarcidae	*Lycodopsis pacifica*	blackbelly eelpout	1.5	
Embiotocidae	*Cymatogaster aggregata*	shiner perch	0.6	
	Embiotoca lateralis	striped seaperch	0.1	
	Rhacochilus vacca	pile perch	0.1	
Bathymasteridae	*Ronquilus jordani*	northern ronquil	0.3	
Stichaeidae	*Lumpenus sagitta*	snake prickleback	0.3	0.2
Scorpaenidae	*Sebastes auriculatus*	brown rockfish	0.1	
	Sebastes caurinus	copper rockfish	a	
	Sebastes maliger	quillback rockfish	0.6	
	Sebastes melanops	black rockfish	a	
Hexagrammidae	*Hexagrammos stelleri*	whitespotted greenling	0.2	
	Ophiodon elongatus	lingcod	0.1	
Cottidae	*Chitonotus pugetensis*	roughback sculpin	0.6	5.6
	Enophrys bison	buffalo sculpin	0.1	
	Leptocottus armatus	Pacific staghorn sculpin	1.1	0.3
	Scorpaenichthys marmoratus	cabezon	a	
Agonidae	*Agonopsis emmelane*	northern spearnose poacher		0.1
	Agonus acipenserinus	sturgeon poacher	a	0.2
Bothidae	*Citharichthys sordidus*	Pacific sanddab	2.7	
	Citharichthys stigmaeus	speckled sanddab	0.4	1.7
Pleuronectidae	*Eopsetta jordani*	petrale sole	a	
	Glyptocephalus zachirus	rex sole	a	
	Hippoglossoides elassodon	flathead sole	3.9	
	Inopsetta ischyra	hybrid sole	a	
	Lepidopsetta bilineata	rock sole	13.8	25.0
	Lyopsetta exilis	slender sole	0.2	0.4
	Microstomus pacificus	Dover sole	7.6	
	Parophrys vetulus	English sole	55.6	65.8
	Platichthys stellatus	Starry flounder	0.4	0.3
	Pleuronichthys coenosus	C-O sole	0.1	0.2
	Psettichthys melanostictus	sand sole	0.4	0.1
		TOTAL CATCH	4,951	1,735

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[a] <0.1 percent.

and altered benthos of most areas sampled in Commencement Bay may be suitable for adult English sole, but largely unacceptable for younger individuals.

At five of the eight Commencement Bay study areas (Blair, Sitcum, St. Paul, Middle, and City Waterways), English sole abundance was more than twice that in Carr Inlet. The Ruston-Pt. Defiance Shoreline was the only study area in which English sole abundance was lower than that in Carr Inlet. These data indicate that, except for the Ruston-Pt. Defiance Shoreline, the Commencement Bay study areas generally attracted considerably more English sole than did the reference area. A possible explanation for this pattern is that most of the Commencement Bay study areas support considerably higher standing crops of English sole prey (i.e., benthic invertebrates) than does Carr Inlet. Studies of English sole in Commencement Bay (Becker 1984) have shown that they prefer as food items the polychaete worms and clams that are enhanced in abundance in the waterways.

The condition (i.e., weight-at-length) of all 1,007 English sole of known sex subsampled for histopathological analysis was compared between Commencement Bay and Carr Inlet using regression analysis. Results showed that the condition of most fish in Commencement Bay exceeded that of fish from Carr Inlet, suggesting that English sole from Commencement Bay were able to obtain and store more energy than were fish from Carr Inlet. Thus, there is no evidence that chemical contamination in Commencement Bay is substantially affecting the condition of resident English sole.

3.1.2.3 Fish Histopathology--

The liver is singled out for pathological and contaminant analyses because it is the organ most closely associated with regulation and storage of many toxic chemicals (Fowler 1982). Also, for English sole in Puget Sound, the liver is the organ most heavily afflicted with pathological disorders (Malins et al. 1980, 1982).

Histopathological analyses were conducted on 1,020 English sole subsampled from 17 trawl transects. Four kinds of liver lesion (i.e., altered tissue) were evaluated microscopically: hepatic neoplasms, preneoplastic nodules, megalocytic hepatosis, and nuclear pleomorphisms. Hepatic neoplasms are tumors that are either benign (adenoma) or malignant (carcinoma). Preneoplastic nodules are lesions thought to irreversibly progress to neoplasms. Megalocytic hepatosis (enlarged cells and nuclei) and nuclear pleomorphisms (enlarged nuclei) are degenerative conditions, but are not known to progress to neoplasms. The causes of the four kinds of liver lesion are unknown. It is possible that they are induced by chemical contaminants in the environment. Morphologically similar lesions have been induced in laboratory mammals and fishes by exposure to toxic and/or carcinogenic chemicals (Malins et al. 1984).

Hepatic neoplasms were found in English sole from every study area except the Ruston-Pt. Defiance Shoreline and Carr Inlet. The highest prevalences of neoplasms were found in Middle (8.3 percent) and Sitcum (5.1 percent) Waterways. Preneoplastic nodules were found in fish from every study area, including Carr Inlet (5.8 percent). As with neoplasms, the highest prevalences of preneoplastic nodules were in Middle (26.7 percent) and Sitcum (18.6 percent) Waterways. Megalocytic hepatosis was found in

English sole from every study area, with Carr Inlet having the lowest prevalence (0.8 percent). Highest prevalences of this condition were in Hylebos (18.3 percent) and Milwaukee (16.7 percent) Waterways. Nuclear pleomorphisms were found in fish from every study area except Milwaukee Waterway and Carr Inlet. Highest prevalences of this disorder were found in Middle (10 percent) and Hylebos (5.6 percent) Waterways.

Fish data were age-corrected because the prevalence of several major lesion types correlated with age of fish and because age composition varied among study areas. Therefore, fish were grouped to allow for comparisons to be made without dependence on fish age. Agecorrected data indicated that, on an embayment basis, prevalences of preneoplastic nodules, megalocytic hepatosis, and nuclear pleomorphisms were significantly higher ($P<0.05$) in Commencement Bay than in Carr Inlet. Hepatic neoplasms were not significantly higher in Commencement Bay than in Carr Inlet. Among the eight Commencement Bay study areas, prevalences of preneoplastic nodules and nuclear pleomorphisms were significantly elevated ($P<0.05$) only in Middle Waterway. Prevalences of megalocytic hepatosis were significantly elevated ($P<0.05$) in Hylebos, Blair, Milwaukee, and Middle Waterways. Based on individual trawl transects within the larger study areas (Hylebos, Blair, and City Waterways and the Ruston-Pt. Defiance Shoreline), prevalences of megalocytic hepatosis were significantly elevated ($P<0.05$) at all three transects in Hylebos Waterway (HY70, HY71, and HY72), at the two inner transects in Blair Waterway (BL70 and HY71), and at the inner transect along the Ruston-Pt. Defiance Shoreline (RS70).

Spatial patterns of English sole having significantly elevated ($P<0.05$) prevalences of one or more of the four kinds of liver lesion are summarized in Figure 7. Significant elevations ($P<0.05$) in lesion prevalences were found in Hylebos, Blair, Sitcum, Milwaukee, and Middle Waterways (based on study areas) and at HY71, HY72, BL71, BL72, and RS70 (based on transects within the larger study areas).

Results of the present study were compared with historical data collected by Malins et al. (1984). Absolute values of the prevalences of hepatic neoplasms, preneoplastic nodules, and megalocytic hepatosis in the present study were generally larger than those found by Malins et al. (1984). However, this discrepancy may largely be the result of different age distributions of English sole sampled by the two studies. In contrast with the absolute values, the relative magnitudes of lesion prevalences across areas were very similar between the two studies. In both studies, prevalences were lowest at reference sites, highest in the Commencement Bay waterways, and intermediate in magnitude along the Ruston-Pt. Defiance Shoreline.

3.1.2.4 Bioaccumulation--

Bioaccumulation studies were conducted to determine if sediment or water contaminants were accumulated in the muscle tissues of fish or shellfish living in Commencement Bay. These data were used as an indicator of biological effects and as the database for predicting possible human health effects from consumption of contaminated seafood. Bioaccumulation studies were conducted on two resident organisms living in close contact with the sediments: English sole (*Parophrys vetulus*) and cancrid crabs (*Cancer* spp.).

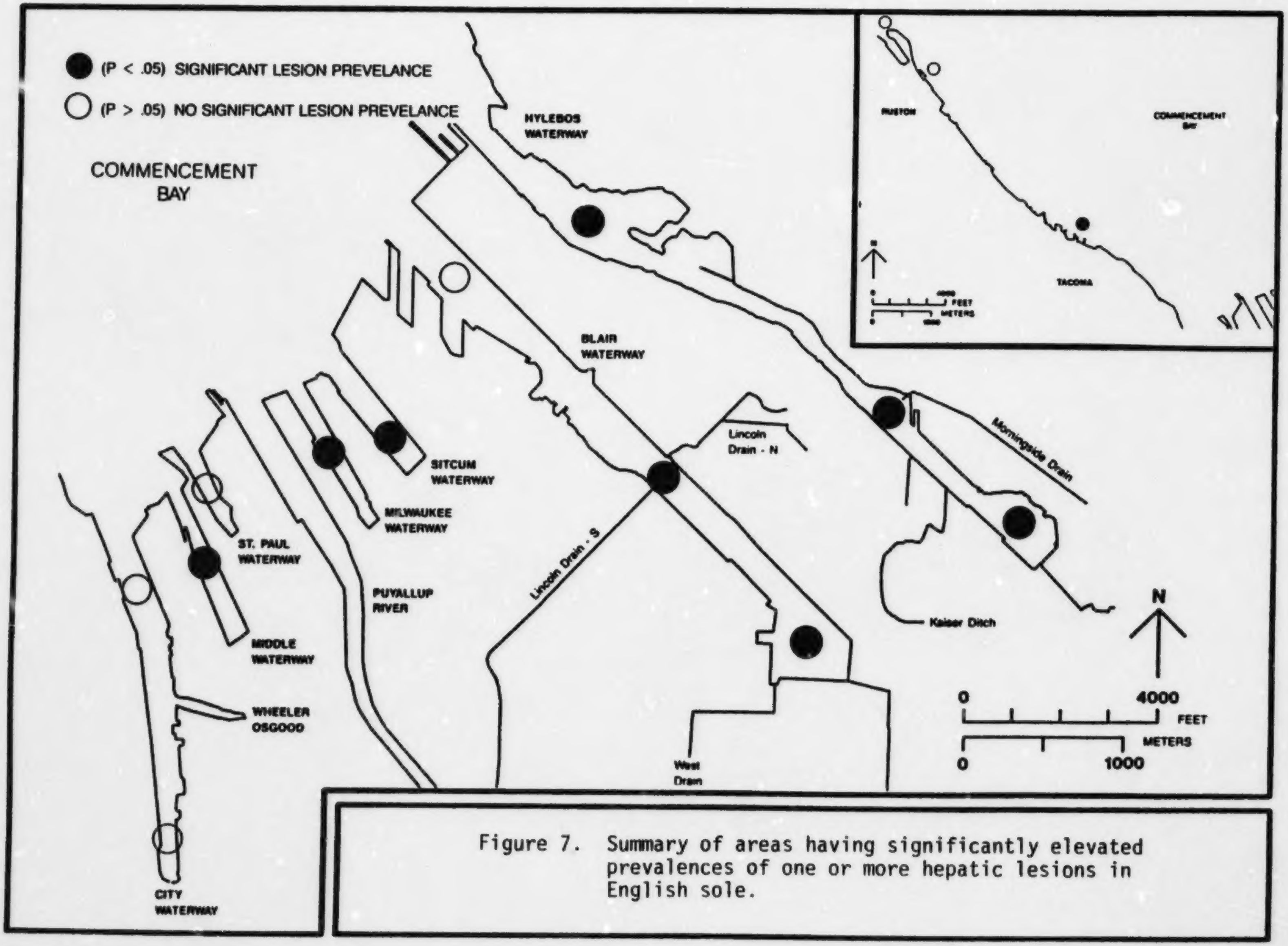
● (P < .05) SIGNIFICANT LESION PREVELANCE
○ (P > .05) NO SIGNIFICANT LESION PREVELANCE
COMMENCEMENT BAY
HYLEBOS WATERWAY
BLAIR WATERWAY
Lincoln Drain - N
Morningside Drain
SITCUM WATERWAY
MILWAUKEE WATERWAY
Lincoln Drain - S
ST. PAUL WATERWAY
PUYALLUP RIVER
Kaiser Ditch
N
MIDDLE WATERWAY
WHEELER OSGOOD
0
4000
FEET
METERS
0
1000
West Drain
CITY WATERWAY
RUSTON
COMMENCEMENT BAY
TACOMA

Figure 7. Summary of areas having significantly elevated prevalences of one or more hepatic lesions in English sole.

Concentrations of metals in English sole muscle tissue were relatively homogeneous among study areas, and there were few cases in which Commencement Bay fish displayed elevated concentrations relative to those in the Carr Inlet reference area. Copper was statistically elevated (3-9 times reference levels) in English sole from Sitcum and St. Paul Waterways and the Ruston-Pt. Defiance Shoreline. The only metals displaying elevated concentrations in Commencement Bay crab muscle tissue were lead and mercury. Maximum lead and mercury concentrations in Commencement Bay crabs were found in Sitcum and Hylebos Waterways, respectively, and were about five times the reference levels. Although arsenic was highly elevated in some Commencement Bay sediments, there was no evidence of excess arsenic accumulation in English sole or crab muscle tissue.

Most of the organic compounds analyzed in this study were not detected in any of the English sole or crab muscle samples. Several compounds, such as some phthalates and volatile substances, were detected at very low concentrations in only a few samples. Eleven organic compounds occurred at sufficient frequency or concentrations to be evaluated for differences in spatial distribution: tetrachloroethene, ethylbenzene, hexachlorobenzene, 1,3-dichlorobenzene, hexachlorobutadiene, naphthalene, bis(2-ethylhexyl) phthalate, di-n-butyl phthalate, di-n-octyl phthalate, DDE, and PCBs.

Hexachlorobenzene and hexachlorobutadiene (both chlorinated compounds) were detected only in English sole from Hylebos Waterway and at concentrations near the method detection limits. Highest concentrations of tetrachloroethene and ethylbenzene (both volatile compounds) also occurred in English sole from Hylebos Waterway. Although the waterway sediments displayed highly elevated concentrations of aromatic hydrocarbons, naphthalene was the only aromatic hydrocarbon detected in fish muscle tissue. These results are consistent with the high rate of metabolism of aromatic hydrocarbons documented for fishes.

PCBs were consistently detected in English sole and crabs from the study area. The maximum concentration of 1,300 ug/kg wet weight was measured in the muscle tissue of English sole from Hylebos Waterway. Highest average concentrations of PCBs exceeded 300 ug/kg wet weight (about 10 times reference levels) and were measured in English sole from Hylebos and City Waterways. Statistically significant PCB elevations in fish muscle tissue were found in Hylebos, City, Sitcum, and Blair Waterways. In the heavily fished Pt. Defiance area, concentrations of PCBs, as well as other organic compounds, were close to reference levels.

3.1.3 Sediment Toxicity

Two separate toxicity tests were used to evaluate the relative toxicity of Commencement Bay sediments: the amphipod mortality bioassay and the oyster larvae abnormality bioassay. The toxicity of Commencement Bay sediments was compared statistically to the toxicity of Carr Inlet sediments. The amphipod bioassay was used to measure a direct lethal response, while the oyster larvae bioassay was used primarily to measure induction of abnormal development in embryos.

Sediments from 18 of the 52 sampling stations were toxic (statistically greater than Carr Inlet, $P<0.05$) to amphipods. Toxic sediments occurred at one or more stations in all study areas except Middle Waterway. Exposure to sediments from 15 of the 52 sites caused significant oyster larvae abnormality ($P<0.05$). Significant oyster larvae abnormality was measured only in Hylebos, St. Paul, and City Waterways, and along the Ruston shore. Overall, 24 of the 52 stations displayed significant responses ($P<0.05$) from one or both of the bioassays (Figure 8).

Ten stations were significantly toxic ($P<0.05$) using both bioassays. Several of these sites also displayed very high (>50 percent) toxicities. These highly toxic sites were concentrated in the following areas: upper Hylebos Waterway, City Waterway, off Champion International near the mouth of St. Paul Waterway, off ASARCO on the Ruston-Pt. Defiance Shoreline, and at a single site off Old Tacoma.

The most toxic sediments tested as part of this study were collected from locations near two industrial sites: the Champion International pulpmill and the ASARCO smelter. It should be noted that the sediments at both of these sites were organically enriched and that the observed toxicities were probably due in part to low dissolved oxygen in the test containers.

In both the amphipod and oyster larvae bioassays, dilution of Commencement Bay test sediments with clean sediment reduced the toxicity. For the amphipod bioassays, a 50-75 percent dilution with control sediment generally was sufficient to reduce mortality to control levels. However, the sediment stations off ASARCO were still highly toxic at a 90 percent dilution. For the oyster larvae bioassay, greater than 75 percent dilutions were required to reduce abnormalities to control levels.

A lower percent of toxic sediments was found in the present study than in past studies. This apparent relationship may be due to one or more of the following factors:

- Overall decline in toxicity over the 5-yr period between surveys

- Lack of sample replication for most historical data

- Differences in sampling station locations: some historical sites were intertidal, while current sites were mainly midchannel (i.e., subtidal).

In several areas, however, there was good agreement between historical and present data. Areas with significantly toxic sediments during both past and present surveys included upper Hylebos Waterway, the head of City Waterway, the area off Champion International near the mouth of St. Paul Waterway, and lower Sitcum Waterway.

3.1.4 Contaminant, Toxicity, and Biological Effects Relationships

Quantitative relationships among the independent contaminant, toxicity, and biological effects variables were evaluated to meet two objectives:

1. To determine levels of sediment contamination above which significant toxicity or biological effects would be expected

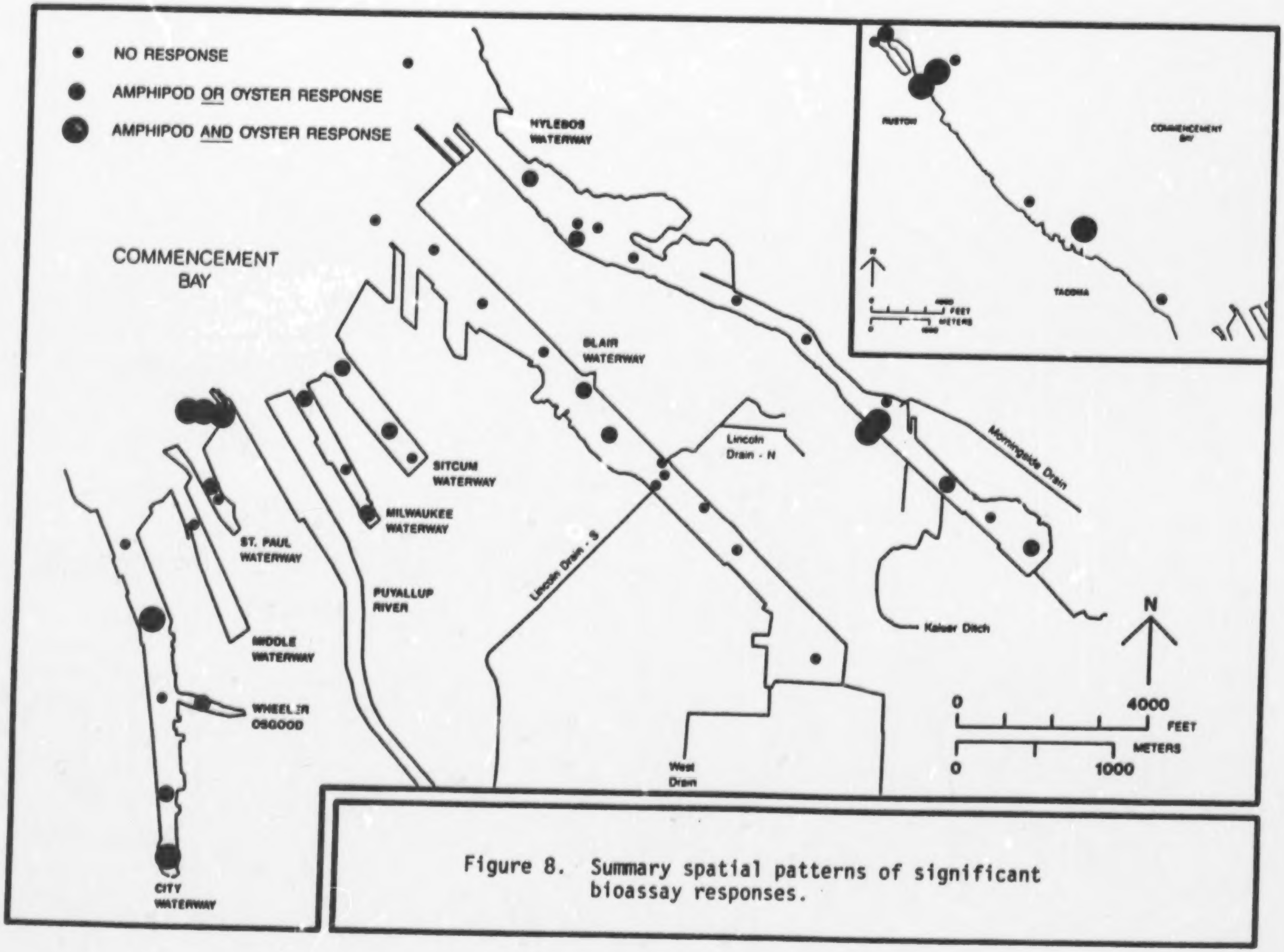
● NO RESPONSE
● AMPHIPOD OR OYSTER RESPONSE
● AMPHIPOD AND OYSTER RESPONSE
COMMENCEMENT BAY
HYLEBOS WATERWAY
BLAIR WATERWAY
SITCUM WATERWAY
MILWAUKEE WATERWAY
ST. PAUL WATERWAY
PUYALLUP RIVER
MIDDLE WATERWAY
WHEELER OSGOOD
CITY WATERWAY
Lincoln Drain - N
Lincoln Drain - S
West Drain
Morningside Drain
Kaiser Ditch
N
0
4000
FEET
METERS
0
1000
RUSTON
COMMENCEMENT BAY
TACOMA

Figure 8. Summary spatial patterns of significant bioassay responses.

2. To identify contaminants of concern from the numerous contaminants detected in Commencement Bay sediments.

Both statistical and nonstatistical approaches were used to evaluate whether toxicity or adverse biological effects increased with increasing sediment contaminant concentrations. In this study, it was assumed that contaminants displaying monotonically increasing relationships with toxic or biological effects have a higher relative priority (i.e., a higher potential for being a causative agent) than do contaminants displaying no discernible relationship with effects.

Where synoptic biological and chemical data were collected, significant toxicity in both the amphipod mortality and oyster larvae abnormality bioassays as well as benthic effects (i.e., depressions of abundance of total taxa, Polychaeta, Mollusca, or Crustacea) were observed at all but one station where the dry-weight concentration of at least one contaminant exceeded 1,000 times reference conditions. The exception was Station HY-43, where trichlorinated butadiene concentrations were nearly 2,000 times reference conditions, but neither bioassay nor any benthic effect was significant. In other sediments without significant toxic responses or benthic effects, concentrations of organic compounds (other than chlorinated butadienes) ranged from 1 to <400 times reference conditions, and concentrations of metals were <50 times reference conditions.

Sediment toxicity and the number of significant benthic effects were highest in the most chemically contaminated study areas. Typically, toxicity increased and abundances of major taxa decreased with increasing concentrations of some contaminants over the entire study area. A common characteristic of these relationships was that at lower chemical concentrations, there was considerable scatter in the magnitude of sediment toxicity and taxon abundances. When trends were observed, the minimum toxicity observed at a given concentration of a chemical increased and the maximum abundances decreased at higher contaminant concentrations. When data from all study areas were plotted together for a given contaminant, there was no clear trend in the values of maximum toxicity or minimum abundances over the concentration range of the contaminant. Thus it is concluded that no one contaminant or contaminant group correlated with the effects observed in all areas.

In some cases, there was random scatter in the values up to a certain contaminant concentration. Above that concentration, there was a rapid change to uniformly high toxicity or low abundances at the few most contaminanted sites. If the high contaminant levels were associated with the effects observed, the abrupt change in the scatter suggested an "effect threshold" for the contaminant.

The synoptic chemical, toxicity, and benthic infaunal data for 52 Commencement Bay stations were examined for each contaminant of concern to evaluate effect thresholds. An example of this approach using lead data is shown in Figure 9. In this case, the available data indicated that significant toxicity or benthic effects did not occur when sediment lead concentrations were below 11 mg/kg dry weight (EAR=1.2). This level defined a "potential effect threshold". This threshold was termed "potential" because toxicity or benthic effects were found at some, but not all, of the stations with higher lead concentrations. The effects observed at these stations could have resulted from other contaminants or conditions.

Toxicity "apparent effect threshold" (AET) was defined as the lowest contaminant concentration above which significant toxicity was observed at all stations. An analogous benthic AET was defined as the lowest contaminant concentration above which significant benthic effects occurred at all stations. For lead, the toxicity AET was 660 mg/kg dry weight (EAR=72) and the benthic AET was 300 mg/kg dry weight (EAR=33) (Figure 9). The effect thresholds were termed "apparent" because significant toxicity or benthic effects were not found at some stations with equal or lower lead concentrations, while significant sediment toxicity or benthic effects were found at all stations with higher concentrations. These empirical relationships do not prove that contaminants found above an AET were responsible for the observed toxicity or benthic effects. However, within the limits of this data set, chemicals present above these concentrations were associated exclusively with problem sediments having significant toxicity or depressed benthic infaunal abundances (or both). Because of this association, all chemicals present above toxicity or benthic AET were defined as problem chemicals requiring further evaluation.

The approach shown in Figure 9 was used to identify toxicity and benthic AET for all chemicals of concern. The AET expressed on a dry-weight basis are summarized for metals, organic compounds, and conventional sediment variables in Table 6.

AET were exceeded by a number of chemicals at most of the 29 stations exhibiting statistically significant biological effects. All six of the 29 stations where neither AET was exceeded were unusual in that only one of the biological indicators showed a response. Most of these six stations exhibited toxicity by the amphipod bioassay only, and the toxicity may have been related to the high percentage of fine-grained material (>80 percent) at each station. The difference in thresholds for toxicity and benthic effects for several chemicals suggests that both bioassays were more sensitive to organic compound contamination, and that benthic depressions were more sensitive to metals contamination.

AET were also calculated for normalizations to organic carbon and percent fine-grained material. For most sediments with multiple toxicity and benthic effects, chemicals exceeded an AET regardless of normalization.

Gradients of effects were analyzed for study areas having a sufficient number of stations with biological measurements to allow such analysis. Five such areas were analyzed. Strong relationships were observed for a few chemicals that were present at concentrations above an AET. Exposure-response relationships were found for:

- PCB concentrations, sediment toxicity, and mollusc abundance along a Hylebos Waterway transect
- 4-Methylphenol concentrations, sediment toxicity, and crustacean abundance along a St. Paul Waterway transect

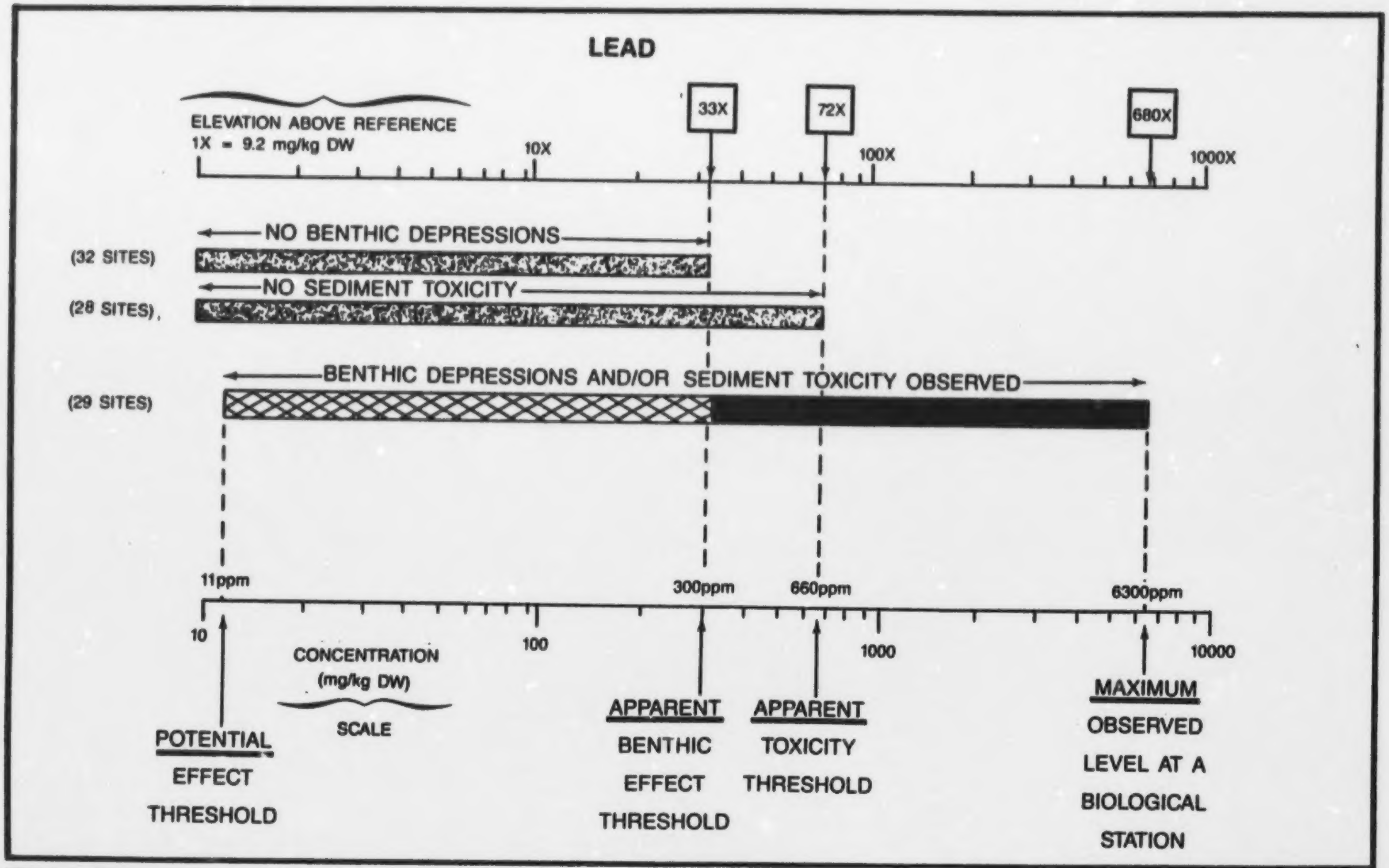

Figure 9. Example use of synoptic benthic effects and sediment toxicity data to determine apparent chemical effect thresholds.

TABLE 6. APPARENT EFFECT THRESHOLDS (AET) FOR SEDIMENT CONTAMINANTS AND CONVENTIONAL VARIABLES

Metals	Toxicity AET (mg/kg DW)	Benthic Effects AET (mg/kg DW)
Antimony	5.3	3.1
Arsenic	93	85
Cadmium	5.8	5.8
Copper	310	310
Lead	660	300
Mercury	0.59	0.52
Nickel	39	39
Zinc	490	260

Organic Compounds	Toxicity AET (ug/kg DW)	Benthic Effects AET (ug/kg DW)
Phenol	420	1,200
2-methylphenol	63	72
4-methylphenol	670	670
LMW aromatic hydroarbons	5,200	5,200
HMW aromatic hydrocarbons	12,000	17,000
Chlorinated benzenes	270	400
Chlorinated butadienes[a]	47,000	47,000
Total phthalates	3,400	5,200
Total PCBs	420	1,100
Benzyl alcohol	130	130
Dibenzofuran	540	540
n-Nitrosodiphenylamine	28	28
Tetrachlorethene	140	140
Ethylbenzene	37	37
Total xylenes	120	120
2-Methoxyphenol	930	930
1,1'-Biphenyl	260	270
Dibenzothiophene	240	250
Pentachlorocyclopentane[a]	72	72
Isopimaradiene	1,500	1,500
Kaur-16-ene (possible id)	2,000	2,000
Retene	1,200	2,000

Conventional Variables	Toxicity AET	Benthic AET
Total volatile solids (%)	22.2	22.2
Total organic carbon (%)	15.1	15.1
Nitrogen	0.28	0.28
Oil and grease (mg/kg)	2,200	4,300

[a] No station exhibiting toxicity or benthic effects had concentrations exceeding these levels

- Organic enrichment (and selected metal concentrations), sediment toxicity, mollusc abundance, and crustacean abundance along a City Waterway transect
- Mercury concentrations and polychaete abundance along the same City Waterway transect noted above
- Mercury, LPAH concentrations, and sediment toxicity along an onshore-offshore Ruston-Pt. Defiance transect
- Most metal and organic compound concentrations with mollusc and polychaete abundances along the same Ruston-Pt. Defiance transect noted above.

These four transects included stations with the most extensive toxicity and benthic effects observed in Commencement Bay. Sediment toxicity tended to correlate better with contaminant concentrations than did benthic effects.

3.2 PUBLIC HEALTH ASSESSMENT

Results of this study and previous investigations have shown that various inorganic and organic contaminants are bioaccumulated by Commencement Bay fishes. The objective of the public health assessment was to determine if there are significant health risks associated with consumption of fish and shellfish from Commencement Bay. This assessment considered only one exposure route (i.e., eating non-salmonid fish, fish livers, and crabs) from Commencement Bay. Other possible exposure routes (drinking water, inhalation) were not included in this assessment.

English sole and cancrid crabs were selected for these analyses because of their availability in the project area and because they live in close association with contaminated bottom sediments. Although English sole are not commonly caught by local fishermen, they were used in the present study to provide a conservative estimate of the maximum contaminant levels that would be expected in edible tissues of any fish species captured in Commencement Bay. Data from a previous study (Gahler et al. 1982) have shown that concentrations of PCBs and arsenic are two to three times higher in English sole than in commonly caught fish such as walleye pollock, Pacific hake, and Pacific cod.

Available data from a catch/consumption survey indicated that 15,220 persons may consume fish from Commencement Bay. Of this total exposed population, only 30 persons were estimated to eat 1 lb of fish per day. This was the highest estimated consumption rate in the survey. Approximately 82 percent of the exposed population (12,500 persons) consumes less than 1 lb of fish per month. For the risk assessment, maximum individual risks of contracting cancer were calculated for the maximum consumption rate, as well as for the more commonly experienced lower consumption rates. Individual risks are expressed mathematically as negative exponents. In such expressions, 10^{-6} would represent a one in one million chance of contracting cancer during a lifetime exposure (i.e., 70 years) to the contaminated fish flesh.

The Commencement Bay public health assessment is highly conservative in that it tends to overestimate any effects of seafood consumption. The following conservative factors are incorporated into the approach:

- U.S. EPA's method estimates upper bounds of carcinogenic risk
- Esposure is assumed to occur continuously for a lifetime (70 years)
- English sole are generally more contaminated than commonly caught sport fish
- The maximum consumption rate of 1 lb/day is probably an overestimate. This rate would require the consumption of two or more meals of Commencement Bay fish every day for a lifetime.

This conservative approach is used because of the overall importance of public health concerns and because of the many uncertainties in the methodology. Given these factors, it is prudent to use such a conservative approach, recognizing that the predicted public health effects are most likely overestimated.

At the maximum estimated consumption rate of 1 lb/day of fish from Commencement Bay, the estimated individual lifetime risks would exceed one in one million (10^{-6}) for six carcinogens: PCBs, arsenic, hexachlorobenzene, hexachlorobutadiene, bis(2-ethylhexyl)phthalate, and tetrachloroethene. At a fish consumption rate of 1 lb/month, only PCBs and arsenic would exceed the one in one million (10^{-6}) risk level. For a given consumption rate, estimated individual risks from consuming Commencement Bay fish muscle would exceed those for consuming Carr Inlet (reference area) fish for three of the above six carcinogens: PCBs, bis(2-ethylhexyl) phthalate, and tetrachloroethene. For PCBs, individual risks from consuming Commencement Bay fish would be about five times higher than those from consuming Carr Inlet fish. For arsenic, estimated individual risks from consuming Commencement Bay fish and Carr Inlet fish would be similar, although Carr Inlet risks would be slightly higher.

Fish tissue concentrations, and hence the associated risk for consuming fish, varied somewhat among the Commencement Bay waterways. For PCBs, the suspected carcinogen representing the greatest individual risk, fish consumed from City and Hylebos Waterways represent the greatest risk. Based on PCB contamination, risks associated with eating fish from Hylebos and City Waterways are about 10 times higher than for fish from Carr Inlet.

Much of the shore fishing in Commencement Bay occurs on piers along the Ruston-Pt. Defiance Shoreline. Therefore, contamination of fish in this area is of special concern relative to possible public health impacts. The available data indicate that risks associated with PCB contamination of fish tissues decrease with distance from City Waterway towards Pt. Defiance. Moreover, estimated individual risks for all chemicals in the Pt. Defiance area are similar to those in the Carr Inlet reference area.

A primary objective of the Commencement Bay project was to determine if the levels of fish tissue contamination resulted in the prediction of one or more excess cancer cases in the exposed population over a 70-year period due to ingested tissue. This assessment was accomplished by applying the individual risks for each carcinogen to the exposed population estimated from the catch/consumption survey. The highest estimated incidence of cancer in the exposed population of 15,220 persons is between one and two cases in 70 years, and is attributable to PCBs causing cancer of the liver. All available data indicate that the chemical group associated with the highest individual lifetime cancer risk is PCBs. The next highest risk is attributable to arsenic. Only for PCBs, however, does the estimated number of cancer cases in the exposed population exceed one, even with the conservative approach taken in this assessment (e.g., continuous exposure for 70 years). Arsenic exposure is estimated to result in fewer than one case over 70 years, and it is the second highest in individual risk. Therefore, aside from PCBs, no other chemical is estimated to produce cancer in the exposed population under the circumstances presented in this assessment.

The risk assessment was also conducted for consumption of crabs in Commencement Bay. For PCBs and arsenic, estimated individual risks for eating crabs were approximately the same as those for eating fish. Only PCBs, however, resulted in a higher risk (about three times higher) for eating Commencement Bay crabs when compared with Carr Inlet crabs.

Three noncarcinogens were present in fish muscle at levels that would cause exposure to exceed the U.S. EPA Acceptable Daily Intake (ADI) at the 1 lb/day consumption rate: antimony, lead, and mercury. Tissue concentrations of these chemicals were very similar among project areas and at the Carr Inlet reference site. Therefore, the ADIs would be exceeded at both Commencement Bay and Carr Inlet for the 1 lb/day consumption rate. Limiting consumption of fish to one-half pound per day would result in an exposure below the ADI for all of these chemicals. However, health risks at this consumption rate would still exist due to the presence of carcinogens in these fishes.

For consumption of crab muscle at the maximum rate of 1 lb/day, calculated exposures exceeded the ADI for the following contaminants: antimony, lead, silver, zinc, and mercury. For these metals, the ADIs were exceeded for crabs from both Commencement Bay and Carr Inlet. For most of the metals, the differences between Commencement Bay and Carr Inlet were slight. By limiting consumption of crabs from either Commencement Bay or Carr Inlet to 1 lb/week, all noncarcinogenic exposures would be below the ADI.

Twenty-one chemicals were detected in at least one fish liver composite sample from Commencement Bay. Four of the detected chemicals are considered to be carcinogens: PCBs, hexachlorobenzene, hexachlorobutadiene, and arsenic. At the maximum consumption rate of 0.12 lb/day, consumption of PCBs in fish liver would result in a predicted individual lifetime risk of two in one hundred ($2x10^{-2}$). This risk is higher than the corresponding risk associated with consumption of PCBs in fish muscle tissue, six in one thousand ($6x10^{-3}$), because of the much higher PCB concentrations in fish livers. The predicted risk level for PCBs in Commencement Bay fish livers is about 15 times higher than the corresponding risk for fish livers from Carr Inlet.

Maximum estimated carcinogenic risks for hexachlorobenzene and hexachlorobutadiene in fish liver were about the same as the corresponding risks for fish muscle [i.e., one in ten thousand (10^{-4}) and one in one hundred thousand (10^{-5}), respectively]. All other estimated carcinogenic risks were much lower than these levels.

All calculated exposures for the noncarcinogens present in fish livers from Commencement Bay were less than 10 percent of the corresponding ADIs. Therefore, even at the maximum consumption rate of 0.12 lb/day, no human health effects attributable to these noncarcinogens would be expected.

Of the chemicals detected in fish livers from Commencement Bay, PCBs pose the greatest potential risk to public health. Although the maximum estimated risk of one in one hundred (10^{-2}) is associated with a high consumption rate, even much less frequent consumption of fish livers would result in a substantial predicted risk.

As a result of the public health assessment, the Tacoma-Pierce County Health Department, in conjunction with the Department of Social and Health Services, issued a revised health advisory. The advisory recommended against the consumption of fish from the Commencement Bay waterways. The advisory also recommended that consumption of fish caught from the southwest shore of Commencement Bay and in Carr Inlet be limited.

3.3 PRIORITIZATION OF PROBLEM AREAS AND CONTAMINANTS

The objective of this part of the Commencement Bay Remedial Investigation was to identify and prioritize problem areas and problem contaminants. This prioritization resulted from the decision-making approach described in Section 2.2.1.

An important part of the decision-making process was the development of action assessment matrices for study areas and segments. The action assessment matrix for the eight Commencement Bay study areas is shown in Table 7. This matrix represents a characterization of the largest scale of contamination and effects considered in this study. Variables are averaged across all stations within each study area. Similar matrices without fish pathology and bioaccumulation results were constructed for waterway segments shown in Figure 5 (Section 3.1.1). Values listed in the matrix represent elevations above reference (EAR), and those enclosed by a box were significant. Chemical significance was defined as an exceedance of the maximum concentration observed in any Puget Sound reference area. Biological significance was based on statistical criteria and an experimentwise error rate of 0.05.

Based on average values over each study area (e.g., Hylebos Waterway) the following conclusions are evident:

- Several organic compounds were significant in all study areas.

- Metals contamination was significant in all areas except St. Paul Waterway.

TABLE 7. ACTION ASSESSMENT MATRIX OF SEDIMENT CONTAMINATION, SEDIMENT TOXICITY, AND BIOLOGICAL EFFECTS INDICES FOR COMMENCEMENT BAY STUDY AREAS

	STUDY AREA ELEVATIONS[a]								
VARIABLE	Hylebos	Blair	Sitcum	Milwaukee	St. Paul	Middle	City	Ruston	REFERENCE VALUE[b]
SEDIMENT CHEMISTRY									
Sb	10.	4.0	8.0	3.6	4.2	9.3	7.0	510.	110. ppb
As	12.	7.6	11.	3.6	2.2	9.6	7.5	620.	3370. ppb
Cd	2.4	1.9	2.8	1.7	1.7	2.8	5.5	27.	950. ppb
Cu+Pb+Zn	10.	4.8	24.	7.3	5.5	18.	22.	120.	35000. ppb
Hg	8.1	< 3.7	5.0	3.8	5.1	26.	10.	160.	40. ppb
Ni	1.4	0.7	0.6	0.8	0.8	0.7	1.4	2.8	1740. ppb
Phenol	< 6.4	< 5.2	4.3	< 2.1	12.	11.	9.4	4.5	< 33 ppb
Pentachlorophenol	1.7	< 2.3	< 2.1	< 0.90	U 1.9	5.6	< 1.9	< 1.0	U 33. ppb
LPAH	<45.	<28.	<68.	<60.	<73.	<110.	<120.	<87.	< 41. ppb
HPAH	<120.	<42.	<65.	<68.	<27.	< 97.	<140.	<85.	< 79. ppb
Chlor. benzenes	9.9	< 4.4	2.6	< 2.5	< 1.8	< 6.1	< 9.0	< 3.3	U 21. ppb
Chlor. butadienes	130.	< 2.7	< 2.4	< 1.2	< 1.3	< 6.8	< 1.9	< 1.7	U 62. ppb
Phthalates	4.0	< 2.6	< 0.58	< 0.66	< 0.56	< 5.1	< 7.1	4.5	< 280. ppb
PCBs	<48.	< 6.3	7.6	6.6	<17.	8.5	<12.	19.	< 6.0 ppb
4-Methylphenol	<7.3	<12.	10.	13.	1300.	< 33.	30.	<10.	< 13. ppb
Benzyl alcohol	5.0	< 2.2	2.4	3.4	< 6.7	3.3	4.7	< 1.2	U 10. ppb
Benzoic acid	< 0.7	< 3.2	< 0.5	< 0.7	< 1.0	U 0.1	< 1.6	< 0.5	< 140. ppb
Dibenzofuran	29.	25.	73.	59.	52.	80.	58.	<160.	U 3.7 ppb
Nitrosodiphenylamine	2.1	< 2.4	< 7.3	U 1.0	U 1.2	< 1.0	14.	<22.	U 4.1 ppb
Tetrachloroethene	12.	< 0.6	U 1.0	---	U 1.0	---	U 1.0	---	U 10. ppb
SEDIMENT TOXICITY									
Amphipod bioassay	2.1	1.9	2.9	2.4	4.8	1.4	2.7	3.9	9.3 %
Oyster bioassay	2.2	1.6	1.3	1.4	3.8	1.8	2.6	2.2	13.0 %
INFAUNA[c]									
Total benthos	1.2	1.0	0.7	0.8	1.9	1.5	0.7	0.6	d
Polychaetes	0.6	1.0	0.4	0.7	1.5	0.7	0.8	0.5	d
Molluscs	3.4	1.0	1.4	1.1	6.8	5.4	2.5	1.2	d
Crustaceans	1.5	1.0	3.8	0.4	1.0	4.6	1.2	0.7	d
FISH PATHOLOGY									
Lesion prevalence	3.6	2.5	3.5	3.7	2.7	5.7	1.7	2.1	6.7 %
FISH BIOACCUMULATION									
Copper	5.6	1.0	4.0	2.3	9.1	1.0	3.8	2.5	U 38. ppb
Mercury	1.5	0.93	0.80	1.6	0.76	1.3	0.82	0.96	U 55. ppb
Naphthalene	0.67	0.41	0.33	24.	0.19	0.19	4.1	0.19	< 54. ppb
Phthalates	21.	11.	0.53	3.6	0.41	0.41	6.7	5.6	< 74. ppb
PCBs[e]	9.2	7.0	4.8	2.8	1.1	4.7	9.8	1.9	< 36. ppb
DDE	3.8	5.1	3.3	3.4	1.7	1.7	6.2	2.9	< 1.8 ppb

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[a] Boxed numbers represent elevations of chemical concentrations that exceed all Puget Sound reference area values, and statistically significant toxicity and biological effects at the P<0.05 significance level compared with reference conditions. The "U" qualifier indicates the chemical was undetected and the detection limit is shown. The "<" qualifier indicates the chemical was undetected at one or more stations. The detection limit is used in the calculations.

[b] Elevation above reference (EAR) values shown for each area are based on Carr Inlet reference values for each variable except for benthos (see footnote d).

[c] Infauna EAR are based on the elevation in biological effects represented by reductions in infaunal abundances relative to reference conditions. EAR for all other variables reflect an increase in the value of the variable at Commencement Bay compared with reference conditions.

[d] Different benthic reference values were used depending on sediment grain size.

[e] Locations where PCB concentrations are significantly elevated also pose a significant health risk to the exposed population (see Table 6.8 guidelines).

- Blair and Milwaukee Waterways had the least chemical contamination based on number and magnitude of significantly elevated chemical indices.

- Sediment toxicity was statistically elevated ($P<0.05$) in all areas except Middle Waterway, as indicated by one or both bioassays.

- Sediment toxicity as indicated by both bioassays was statistically elevated only in Hylebos and City Waterways.

- Benthic effects as indicated by depressions in infaunal abundances were statistically significant ($P<0.05$) in Hylebos, Sitcum, St. Paul, Middle, and City Waterways.

- Liver lesions were significantly elevated ($P<0.05$) in all study areas except St. Paul and City Waterways and the Ruston-Pt. Defiance Shoreline.

- Bioaccumulation of at least one chemical in English sole muscle tissue was significantly elevated ($P<0.05$) in all study areas except Middle Waterway.

Evaluation of waterway segments defined in Section 3.1.1 indicated that contamination, toxicity, and benthic effects were heterogeneous within the large study areas (i.e., those areas containing more than one segment). For example, although Hylebos Waterway as a whole exhibited the largest number of significant indicators, and chemical contamination was evident throughout the waterway, there was no significant toxicity in Segments HYS3 or HYS4, and no significant benthic effects in Segments HYS3 or HYS6. In general, chemical contamination in Hylebos Waterway was most extensive at the head of the waterway, with additional high values for selected chemicals in Segment HYS5 near the mouth of the waterway. Relatively low levels of chemical contamination were observed in Blair Waterway as compared to the other areas. These lower contaminant levels corresponded to a lack of significant toxicity or benthic effects indicators when averaged over any segment. Within City Waterway, contamination, toxicity, and benthic effects were highest near the head (Segment CIS1) and within the Wheeler-Osgood branch of the waterway (Segment CIS2). The mouth of City Waterway (Segment CIS3) was comparable in number and magnitude of significant indicators to Segment RSS1 along the eastern Ruston-Pt. Defiance Shoreline. The extreme metals contamination and high level of organic compound contamination within Segment RSS2 corresponded to the largest number and highest average magnitude of toxicity and benthic effects indicators along the Ruston-Pt. Defiance Shoreline.

Action-level guidelines specified in the decision-making approach were applied to the action assessment matrices to determine problem areas. One of the guidelines specified that if significant elevation in any three of the five indicators (sediment chemistry, sediment toxicity, infauna, fish pathology, bioaccumulation) occurred, then a problem area was indicated. Use of this guideline resulted in the designation of problem areas in all Commencement Bay study areas and segments. Several of the segments within the larger study areas met this criterion only when study-area wide values for fish pathology and bioaccumulation were considered. According to the guidelines, significant bioaccumulation of PCBs in Hylebos, Blair, Sitcum, and City Waterways warrants source identification based solely on the prediction of possible significant health effects.

Among the large study areas (i.e., Hylebos, Blair, and City Waterways, and the Ruston-Pt. Defiance Shoreline) six segments within these areas had significant EAR for all three of the site-specific indicators (contamination, sediment toxicity, and benthic effects), including:

- Segments HYS1, HYS2, and HYS5 in Hylebos Waterway
- Segments CIS1 and CIS2 in City Waterway
- Segment RSS2 along the Ruston-Pt. Defiance Shoreline.

Of the small study areas, Sitcum and St. Paul Waterways had significant EAR for these indicators.

A problem area was also indicated in Segment HYS4 of Hylebos Waterway, because mollusc abundances were depressed more than 95 percent relative to reference conditions (i.e., EAR >20). According to the guidelines, this condition indicated a problem area regardless of the values for other indicators.

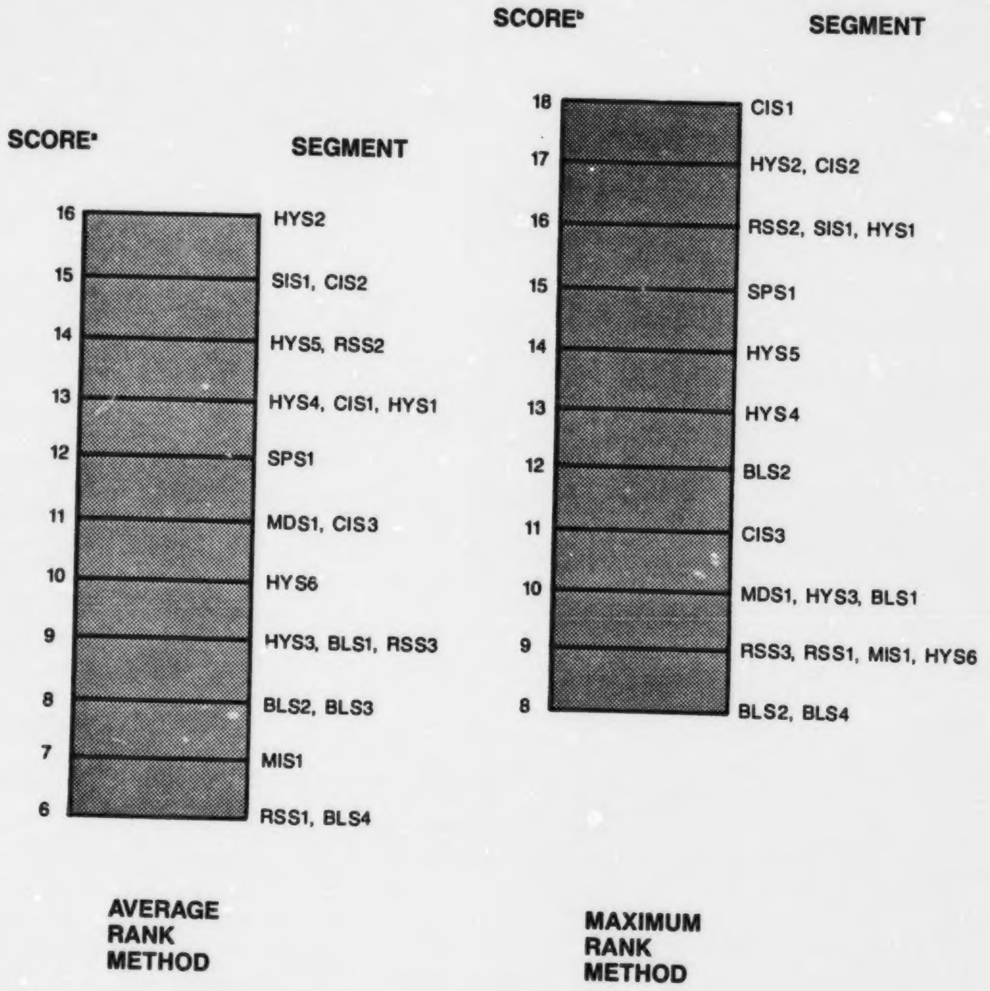
Because all study areas and segments exceeded the action-level guidelines for further definition of problem areas for source evaluation, an independent ranking procedure was applied to the data to prioritize study areas and segments. Results of the ranking procedure are presented for study areas in Table 8 (for explanation of ranking procedures, see Volume 1). For segments, ranks based on the average and maximum conditions are shown in Figure 10. According to these ranking procedures, segments in Hylebos, Sitcum, and City Waterways, and Segment RSS2 along the Ruston-Pt. Defiance Shoreline consistently scored high based on contamination and effects. Milwaukee Waterway, four Blair Waterway segments, and Segment RSS1 on the eastern Ruston-Pt. Defiance Shoreline were consistently low in the ranking.

The spatial extent of problem areas within the prioritized segments was established using the chemical data set and quantitative relationships among sediment contamination, toxicity, and biological effects [i.e., the "apparent effects thresholds" (AET)]. AET levels were applied to stations with only chemical data to help define the extent of problem areas. Historical chemical data as well as project data were used. Historical amphipod bioassay data indicating high toxicity (>50 percent mortality) were also used, where available, to define problem area boundaries. The interpolation of chemical concentrations was attempted between stations because of the often patchy distribution of problem sediments. However, when no data were available for nearshore subtidal and intertidal sediments, the problem areas were assumed to extend to the shore.

The spatial extent and general priority for source evaluation of all problem areas identified in Commencement Bay are summarized in Figure 11. At the highest priority sites, all three site-specific indicators were significant. Of the 21 problem areas, eight received the highest priority

TABLE 8. RANKING OF STUDY AREAS BASED ON MAGNITUDE AND NUMBER OF SIGNIFICANT CONTAMINANTS, SEDIMENT TOXICITY, AND BIOLOGICAL EFFECTS

Sediment Contamination		Toxicity/Biological Effects
Ruston	(Highest)	Sitcum
Hylebos		Hylebos
City		City
Middle		Blair
Sitcum		Middle
St. Paul		Milwaukee
Blair		St. Paul
Milwaukee	(Lowest)	Ruston



[a] SCORES ARE SUMS FOR CHEMICAL AND BIOLOGICAL INDICATORS FROM TABLES 6.10 AND 6.11

[b] SCORES ARE SUMMARIZED IN TABLE 6.12

Figure 10. Relative ranking of study area segments by average and maximum observed contamination toxicity, and biological effects.

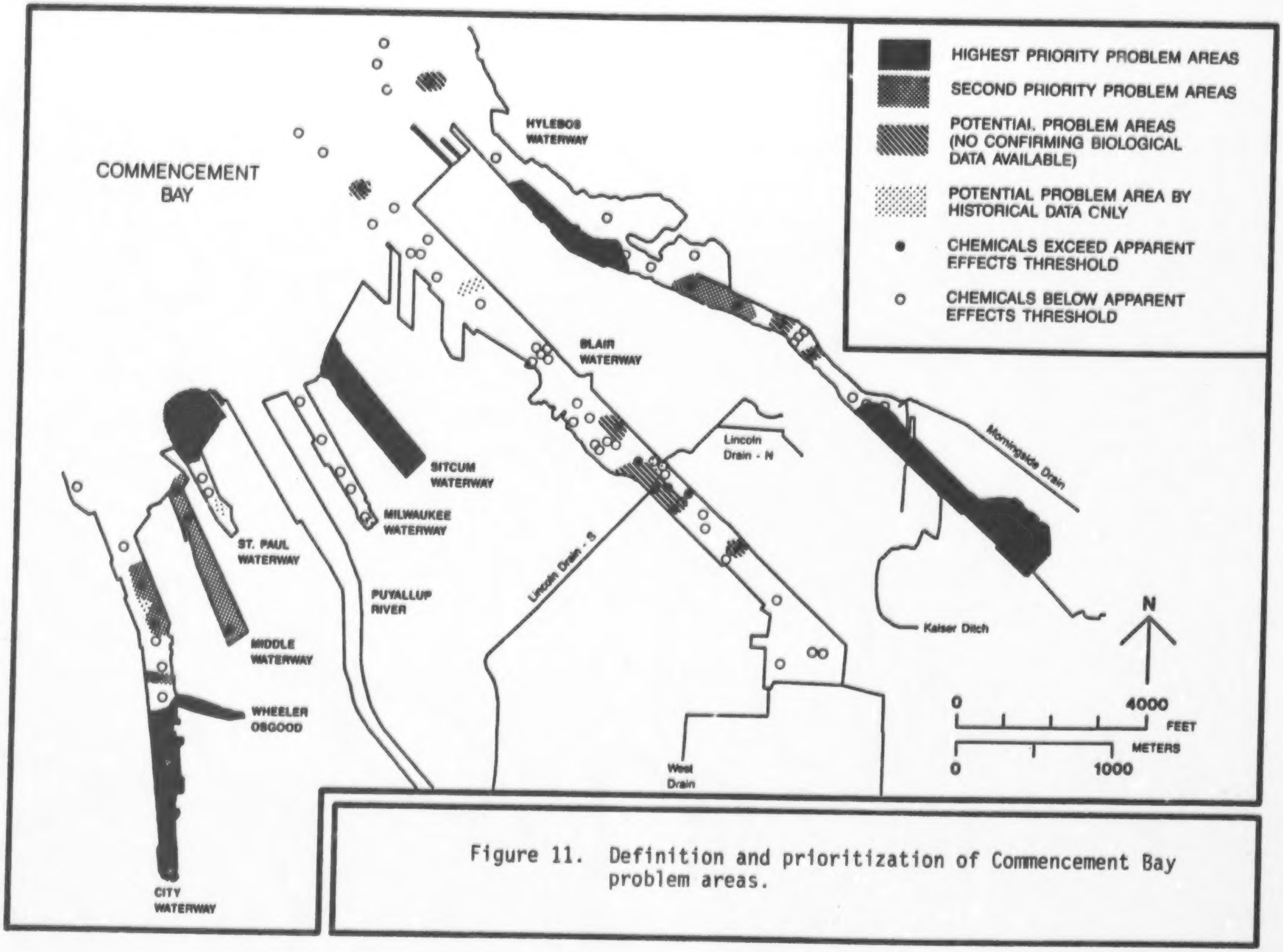

COMMENCEMENT BAY
HYLEBOS WATERWAY
BLAIR WATERWAY
SITCUM WATERWAY
MILWAUKEE WATERWAY
PUYALLUP RIVER
ST. PAUL WATERWAY
MIDDLE WATERWAY
WHEELER OSGOOD
CITY WATERWAY
Lincoln Drain - N
Lincoln Drain - S
West Drain
Morningside Drain
Kaiser Ditch
HIGHEST PRIORITY PROBLEM AREAS
SECOND PRIORITY PROBLEM AREAS
POTENTIAL PROBLEM AREAS (NO CONFIRMING BIOLOGICAL DATA AVAILABLE)
POTENTIAL PROBLEM AREA BY HISTORICAL DATA ONLY
CHEMICALS EXCEED APPARENT EFFECTS THRESHOLD
CHEMICALS BELOW APPARENT EFFECTS THRESHOLD
N
0
4000
FEET
METERS
0
1000

Figure 11. Definition and prioritization of Commencement Bay problem areas.

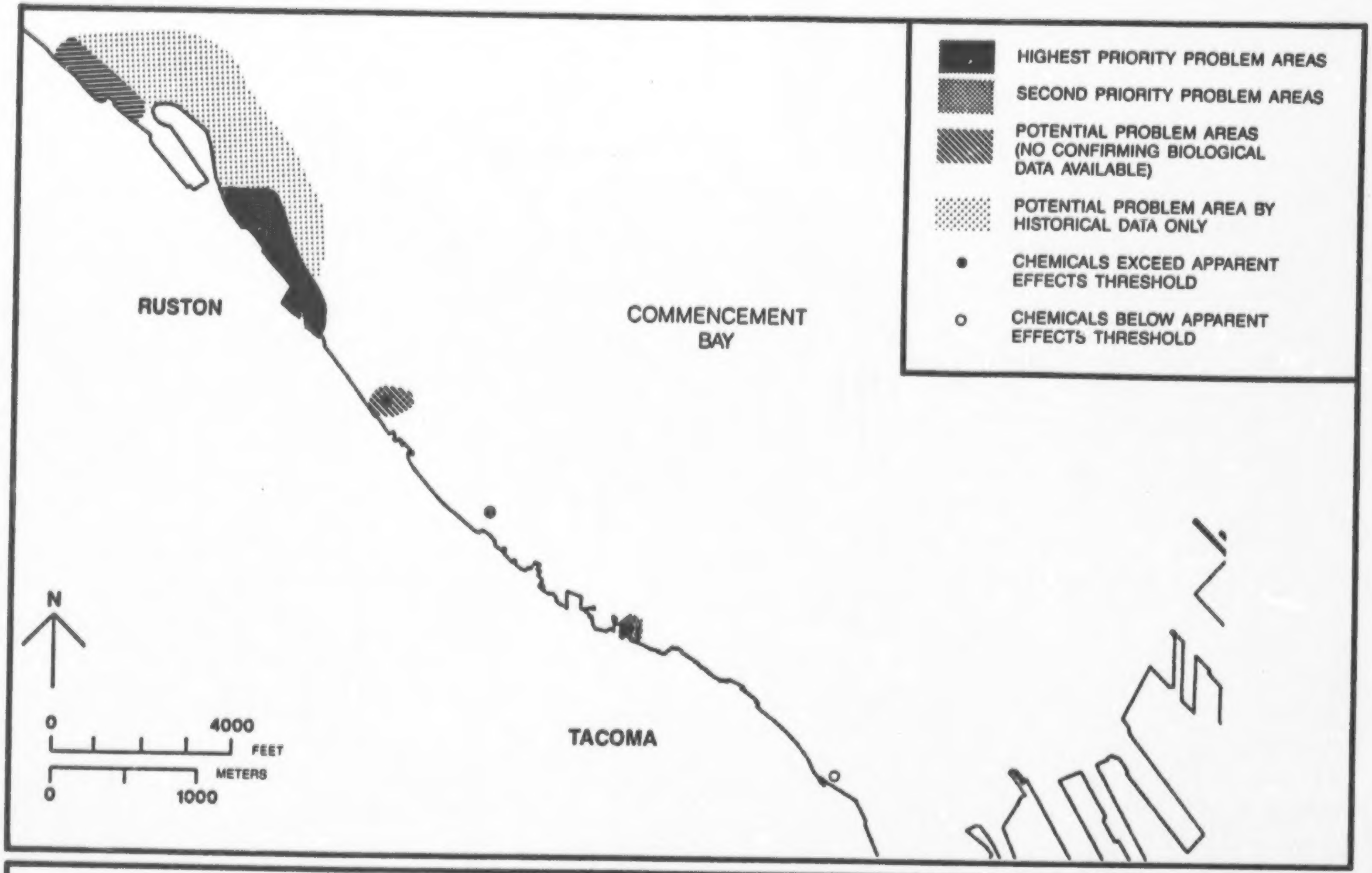

HIGHEST PRIORITY PROBLEM AREAS
SECOND PRIORITY PROBLEM AREAS
POTENTIAL PROBLEM AREAS (NO CONFIRMING BIOLOGICAL DATA AVAILABLE)
POTENTIAL PROBLEM AREA BY HISTORICAL DATA ONLY
CHEMICALS EXCEED APPARENT EFFECTS THRESHOLD
CHEMICALS BELOW APPARENT EFFECTS THRESHOLD
RUSTON
COMMENCEMENT BAY
TACOMA
N
0
4000
FEET
METERS
0
1000

Figure 11. (Continued).

for source evaluation, including three within Hylebos Waterway, two within City Waterway, and one within Sitcum Waterway, one within St. Paul Waterway, and one along the Ruston-Pt. Defiance Shoreline. The second priority sites are "hot spots" where chemical contaminants exceeded an AET, and both bioassays were significant or multiple benthic depressions were observed within the problem area. Four problem areas received second priority for source evaluation, including one within each of Hylebos, Middle, and City Waterways, and at Station RS-13 along along the eastern Ruston-Pt. Defiance Shoreline. Third priority sites include those where chemical contaminants exceeded an AET, and one of the bioassays was significant or a single benthic taxon was significantly depressed. The lowest priority sites for source evaluation include those areas where no sediment toxicity or benthic effects were observed but where AETs applied to available chemical data suggested that toxicity or benthic effects would have been found had biological data been collected.

Chemicals of concern were defined in Section 3.1.1 as chemicals with concentrations exceeding all Puget Sound reference conditions. These chemicals were not necessarily considered problem chemicals because most sediments in Commencement Bay were contaminated above reference conditions and only some of these sediments exhibited toxicity or benthic effects. Although source evaluations may be conducted on all chemicals of concern, it is important to further evaluate these contaminants to identify chemicals posing the greatest environmental hazard. This further prioritization of chemicals is based on the toxicity and benthic AET identified in Section 3.1.4. Because these AET were defined as the contaminant concentrations above which toxicity or benthic effects were always observed, chemicals present above these thresholds were considered problem chemicals.

Problem chemicals were further prioritized into three categories:

- Priority 1: Present above an AET with distribution corresponding to observed toxicity or benthic effects gradients
- Priority 2: Present above an AET at more than one station in the problem area with no apparent relationship to toxicity or benthic effects gradients, or insufficient effects data were available for evaluation of gradients
- Priority 3: Present above an AET at only one station within the problem area.

Priority 1 chemicals for each of the segments containing the eight highest priority problem areas are listed in Table 9. Six of the eight problem areas contained Priority 1 problem chemicals. Within the Priority 1 groups for each problem area, chemicals are listed in descending order of their "toxicity significance factors." These factors represent a combined index of the literature values of the potential mammalian toxicity and the potential for contaminant uptake by marine organisms. All Priority 1 chemicals are recommended for source evaluation. No Priority 1 chemicals were identified for the remaining 12 problem areas. For 10 of these areas, there were not enough stations to establish correspondence between toxicity or benthic effects and sediment contamination.

TABLE 9. POTENTIAL PROBLEM CHEMICALS IN PROBLEM AREAS

Segment Containing Problem Area[a] (in rank order)	Potential Problem Chemicals[b]
CIS1	Priority 1: Hg, Zn, Pb [TOC[d]][c] Priority 2: HPAH, Cd, Ni, Cu, LPAH, 2-methylphenol, 4-methylphenol, phthalate esters [oil & grease][c] Priority 3: dichlorobenzenes, N-nitrosodiphenylamine, [aniline, benzyl alcohol][c]
HYS2	Priority 1: PCBs Priority 2: HPAH, Ni, As, tetrachloroethene [Hg[e], Cu[e], Zn[e], Pb[e] (intertidal sediments only)] Priority 3: HCBD, chlorinated benzenes, phthalate esters, phenol [benzyl alcohol, dibenzothiophene, methylphenanthrenes, methylpyrenes][c]
CIS2	Priority 1: none Priority 2: HPAH, Cd, Cu[e], Zn, dichlorobenzenes, LPAH[e], Pb, N-nitrosodiphenylamine, 4-methylphenol, phenol [biphenyl, TVS, TOC, oil & grease][c]
RSS2	Priority 1: Hg, As, LPAH Priority 2: HPAH, PCBs, Cd, Ni, Cu, Zn, Pb, Sb [dibenzofuran][c] Priority 3: dichlorobenzenes, N-nitrosodiphenylamine, 2-methylphenol, 4-methylphenol, phthalate esters, [1-methyl-(2-methylethyl)benzene, biphenyl, dibenzothiophene, methylphenanthrenes, retene, methylpyrenes][c]
SIS1	Priority 1: none Priority 2: As[e], Cu[e], Zn, Pb Priority 3: N-nitrosodiphenylamine [dibenzofuran, 1-methyl-(2-methylethyl)benzene, diterpenoid hydrocarbons][c], LPAH, HPAH
HYS1	Priority 1: HPAH, As, Zn (limited evidence of a gradient for each with one or more toxicity/effects indicator) Priority 2: phenol, Sb Priority 3: Phthalate esters, ethylbenzene, tetrachloroethene, [xylenes, 1-methyl-(2-methylethyl)benzene, methylpyrenes, TVS][c]
SPS1	Priority 1: 4-methylphenol Priority 2: [benzyl alcohol, 1-methyl(2-methylethyl)benzene, 2-methoxyphenol][c] Priority 3: Ni, LPAH, 2-methylphenol, phenol [biphenyl, diterpenoid hydrocarbons, retene, TVS, TOC][c]

TABLE 9. (Continued)

HYS5	Priority 1:	PCBs
	Priority 2:	HCBD, chlorinated benzenes, chlorinated ethenes [pentachlorocyclopentane isomer][c], Pb
	Priority 3:	Hg, HPAH[e], Cu[e], Zn[e], LPAH[e], phenol [benzyl alcohol, biphenyl][c]
HYS4 (hotspot)	Priority 1:	none
	Priority 2:	none
	Priority 3:	HPAH[e], PCBs[e], HCBD, LPAH[e], N-nitrosodiphenylamine [benzyl alcohol, dibenzofuran[e], pentachlorocyclopentane isomer, methypyrenes][c]
BLS2 (no action)	Priority 1:	none
	Priority 2:	dichlorobenzenes, N-nitrosodiphenylamine, 4-methylphenol, phenol
	Priority 3:	As, HCBD, pentachlorophenol, 2-methylphenol, oil & grease
CIS3 (hotspot)	Priority 1:	none
	Priority 2:	HPAH, LPAH
	Priority 3:	PCBs[e], Zn[e], phenol [biphenyl, dibenzothiophene][c]
MDS1	Priority 1:	none
	Priority 2:	Hg, Cu
	Priority 3:	HPAH, As, Zn, dichlorobenzenes, LPAH, pentachlorophenol, Pb, 4-methylphenol, phenol [dibenzothiophene, diterpenoid hydrocarbons, methylpyrenes][c]
HYS3 (no action)	Priority 1:	none
	Priority 2:	PCBs, As, Zn
	Priority 3:	n-Nitrosodiphenylamine
BLS1 (no action)	Priority 1:	no toxicity/effects observed at stations tested
	Priority 2:	none
	Priority 3:	HPAH, phenol
RSS3 (hot spot)	Priority 1:	none
	Priority 2:	As, Cd, Cu, Zn, Pb, N-nitrosodiphenylamine, Sb
	Priority 3:	none
RSS1 (hot spots)	Priority 1:	none
	Priority 2:	none
	Priority 3:	Station RS-13 hotspot: HPAH, dichlorobenzenes, LPAH, 2-methylphenol, 4-methylphenol [dibenzofuran, biphenyl, methylphenanthrenes, retene, methylpyrenes][c] Station RS-15 hotspot: As, HCBD, Cd, Ni, Cu, Zn, phenol (these chemicals exceed AET at RS-15 only after normalization to percent fine-grained material or to organic carbon content)

TABLE 9. (Continued)

MIS1 (no action)	No chemicals found above apparent effect levels at stations sampled in Milwaukee Waterway	
HYS6 (no action)	Priority 1: Priority 2: Priority 3:	no toxicity/effects observed at station tested none phthalate esters
BLS3 (no action)	Priority 1: Priority 2: Priority 3:	no toxicity/effects observed at stations tested none pentachlorophenol, 2-methylphenol, 4-methylphenol
BLS4 (no action)	Priority 1: Priority 2: Priority 3:	no biological data available none phthalate esters

[a] Problem areas encompass all stations sampled in 1984 only in Segments HY S1, SIS1, CIS1, RSS2, RSS3, and possibly MDS1 (Station MD-12 in this segment was close to apparent effect thresholds for several chemicals).

[b] Concentrations of these chemicals exceeded an apparent effect threshold (by various normalizations) in sediment from at least one station in the defined problem area. Chemicals are listed in each priority group in descending order of their calculated toxicity significance factor, if available. Stations with and without biological data area included. Priority 1 chemicals showed a concentration gradient with toxicity or biological effects gradients. Priority 2 chemicals were above apparent effect thresholds at more than one station within the problem area, but either no gradient corresponding to that for toxicity/effects was observed, or no biological data were available to assess gradients. Priority 3 chemicals were above apparent effect thresholds at one station only within the problem area.

[c] Toxicity significant factors were not available for the chemicals listed in brackets. These chemicals have not been prioritized relative to other chemicals in the same priority group.

[d] TOC concentrations did not exceed an AET in the problem area defined in Segment CIS1 but the TOC concentration gradient corresponded with observed changes in effects (e.g., sediment toxicity). This correspondence may result from the covarying distribution of TOC with other contaminants, including lead and zinc.

[e] Chemical elevated above an AET in the defined problem area only on the basis of historical data.

Priority 2 chemicals were identified in all eight of the highest priority problem areas. Priority 2 chemicals were also identified in three of the lower priority problem areas. Priority 2 chemicals include:

- Cadmium, nickel, and antimony
- Hexachlorobutadiene, chlorinated benzenes, chlorinated ethenes, phenol, 2-methylphenol, n-nitrosodiphenylamine, dibenzofuran, and selected phthalate esters
- Selected tentatively identified compounds.

Priority 2 chemicals are recommended for source evaluation where sufficient spatial data are available to indicate sources.

Priority 3 chemicals not already identified in the Priority 2 group included pentachlorophenol, aniline, and selected tentatively identified compounds. These chemicals are not recommended for source evaluations unless their occurrence at a single station in a problem area is associated with a potential source that is not necessarily indicated by other problem chemicals.

3.4 SOURCE INVESTIGATIONS

Source investigations were conducted for all of the highest priority and second priority problem areas identified in Figure 11. These 12 problem areas are located in Hylebos (4 areas), St. Paul (1 area), Middle (1 area), City (3 areas), and Sitcum Waterways (1 area) and along the Ruston-Pt. Defiance Shoreline (2 areas). Some of these problem areas are adjacent to each other and are not distinguished in Figure 11 (e.g., two high priority problem areas near the head of Hylebos Waterway). Each area is discussed in the following section. Detailed source investigations have not been conducted for the remaining lower priority problem areas shown in Figure 11 and these areas are not discussed.

The contaminants of concern subjected to source evaluations were specific to each problem area. Potential sources that have been evaluated for the contaminants of concern include contaminated groundwater, surface water runoff, spills, and industrial discharges. It should be noted that most of the contaminants of concern discussed in this report are not typically regulated under existing NPDES permits.

3.4.1 Hylebos Waterway

Source identifications were conducted for nine contaminants or contaminant groups for the four problem areas identified in Hylebos Waterway. Of these, one or more sources could be identified for chlorinated hydrocarbons, aromatic hydrocarbons, and metals. The source or sources of PCBs in Hylebos Waterway could not be clearly identified as historical or ongoing. There is evidence that exposure of historically contaminated sediments may be contributing to the patchy distribution of PCBs in Hylebos Waterway.

Occidental Chemical Corporation is implicated as the major source of chlorinated hydrocarbons (chlorinated benzenes, butadienes, and ethenes) to Hylebos Waterway. Historically, the chlorinated organic compounds have entered the waterway via direct discharge from the chlorine production facilities and the solvents plant. They have also entered the waterway via groundwater as a consequence of spills and on-site waste disposal. At present, the chlorinated ethenes, benzenes and butadienes are entering the waterway principally through groundwater and, to a lesser extent, through the main outfall.

Pennwalt Corporation appears to be a current source of chlorinated ethenes, arsenic, copper, lead, and zinc. The chlorinated ethenes are presently being discharged to the waterway through the main plant outfall and through groundwater that has become contaminated as a result of past on-site waste disposal. Arsenic is presently entering the waterway via the main outfall and through groundwater that has become contaminated as a result of on-site disposal of a sodium arsenite pesticide.

Kaiser Aluminum and Chemical has historically been a major source of high molecular weight PAH to Hylebos Waterway, principally via discharge through Kaiser Ditch. Discharge of PAH through this ditch has historically been much greater than it is at present, but there is evidence that some release of PAH continues. Kaiser Ditch is also a source of arsenic and metals. The relative contributions of Kaiser Aluminum and other properties bordering the ditch are unknown.

Hylebos Creek is an ongoing source of arsenic, copper, lead, and zinc. The U.S. Gypsum landfill and the B&L Landfill are major contributors to the arsenic load in Hylebos Creek, although the arsenic contribution from the U.S. Gypsum landfill should decrease with time as a result of recent remedial action. Fife Ditch is the major contributor of zinc to Hylebos Creek.

The six unpaved or partially paved log sort yards bordering Hylebos Waterway are sources of arsenic, copper, lead, and zinc because of the use of ASARCO slag as ballast. High concentrations of these metals were present in the runoff from the yards. As a group, these log sort yards contribute approximately 11 lb/day of arsenic and 11 lb/day of metals (copper, lead, and zinc) via surface runoff (contribution of Dunlap Towing not quantified nor included in total loading). Additional loading from the log sort yards via groundwater could be significant but is unquantified. U.S. EPA acute water quality criteria were exceeded for zinc and copper in Hylebos Waterway near two of the log sort yards.

3.4.2 St. Paul Waterway

Evaluation of contaminant sources for the problem area identified off the mouth of St. Paul Waterway indicates that Champion International (formerly St. Regis Paper Company) is the major source of the contaminants of concern, including alkylated phenols, methoxyphenols, copper, and organic enrichment. Levels of copper measured in the water column in this area have been reported to sometimes exceed water quality criteria. The toxicity and benthic effects AET for copper concentrations in sediment samples was not exceeded. The proximity of the most contaminated sediments to the firm's main outfall indicates that this discharge is the route of contaminant input. The source of these contaminants is ongoing and none of the contaminants of concern resulted strictly from historical discharges.

3.4.3 Middle Waterway

Of the six contaminants or contaminant groups of concern in Middle Waterway, possible sources for three (pentachlorophenol, copper, mercury) have been identified. It is possible that the dichlorobenzenes and PAH are entering the waterway via the storm sewer system or possibly one of the other discharges at the head of the waterway, but the ultimate source or sources within the drainage area could not be identified.

Five industries have been identified as possible sources based on their possible use of products containing the contaminants of concern and their potential discharge to areas of the waterway showing the highest sediment contaminant concentrations. These industries include:

- Champion International (formerly St. Regis Paper Company) - potential unconfirmed source of pentachlorophenol via the storm sewer system (may account for high sediment concentrations near the drain at the head of the waterway)
- Coast Craft - potential unconfirmed source of pentachlorophenol (used as a wood preservative) by spillage or other unauthorized discharge
- Cook's Marine Specialties (formerly Peterson Boat), Foss Tug, and Marine Industries Northwest - potential sources of copper and mercury by release of antifouling paints, sandblasting material, or other products used in ship repair
- Paxport Mills - potential source of metals and organic compounds from a wood waste and ASARCO slag mixture used as fill in a salmon enhancement area near the waterway mouth.

3.4.4 City Waterway

Source investigations were conducted for three problem areas and nine contaminants or contaminant groups of concern in City Waterway. Several industries and storm drains have been identified as probable contributors of metals, PAH, or total organic carbon (TOC) to City Waterway. Sources of dibenzofuran are presumed to be the same as those for PAH. No sources were conclusively identified for PCBs, 1,4-dichlorobenzene, or 1,2-dichlorobenzene.

The Nalley Valley and south Tacoma drains are the major contributors of many of the contaminants of concern to City Waterway. They are ongoing sources of all metals of concern in the waterway, contributing 87, 88, and 81 percent of the quantified loading of lead, copper, and zinc, respectively. One or both of these drains is also the major historical and potentially ongoing source of organic material to the waterway. Finally, the two drains are probably also a major ongoing source of PAH to City Waterway.

Discharge from the 15th Street drain contributes metals and PAH to the waterway, but in much lower amounts than the two storm drains at the head of the waterway because of its much smaller drainage basin and lower average flows.

Hygrade Foods and/or its predecessor, Carsten's Packing Company, appear to be responsible for historical organic enrichment in Wheeler-Osgood Waterway. Both were major dischargers of organic material. The potential of continuing periodic discharges from Hygrade Foods is possible, as is natural decay of accumulated organic debris in the anoxic basin. Storm drains to Wheeler-Osgood Waterway are sources of copper, lead, and zinc. There may be other sources of metals to the waterway as well. Possible sources of 4-methylphenol to the Wheeler-Osgood Waterway are groundwater from the Tar Pits, and degradation of wood chip debris in the sediments.

Martinac Shipbuilding is a probable source of copper and zinc to City Waterway. Sandblasting and antifouling paints are suspected contributors to the contamination. North Pacific Plywood, Puget Sound Plywood, the Tar Pits, and the 23rd and A Street coal gasification site are all possible sources of 4-methylphenol to City Waterway. Input from North Pacific Plywood may have occurred via groundwater or from spills of phenolic glues which entered the storm sewer leading to the 15th Street drain. Glue wastes from Puget Sound Plywood may be contributing to elevated sediment levels of 4-methylphenol found near the mouth of City Waterway. The 23rd and A Street site and possibly the Tar Pits are potential ongoing sources of 4-methylphenol and LPAH through groundwater.

D Street petroleum facilities contribute low molecular weight aromatic hydrocarbons to City Waterway via shallow groundwater that seeps out of the bank near that facility. It is apparent that the problem has been ongoing for at least 12 years. Sediments near the D Street site are contaminated by PAH characteristic of combustion sources, while the groundwater is contaminated mainly by petroleum compounds. Therefore, no relationship could be established between the chemical contamination of groundwater and contamination of sediments in the area. The D Street facilities do not appear to be a source of sediment HPAH contamination near the waterway mouth, although the actual source or sources of these compounds have not been identified.

3.4.5 Ruston-Pt. Defiance Shoreline

Source investigations were conducted at two problem areas along the Ruston-Pt. Defiance shoreline: a single-station hot spot and a larger area adjacent to the ASARCO smelter. Eleven contaminants or contaminant groups were subjected to source evaluations.

At the hot spot, no sources (including nearby properties and drains) were identified for the contaminants identified in sediments. It is possible that historical discharges from a local drain may have contributed to the contamination.

With the possible exception of PCBs, sediment contamination near the ASARCO facility can be attributed to the ASARCO property. The firm has been documented to be a major source of arsenic and metals, with the plant's three NPDES-permitted outfalls alone contributing 780 lb/day of arsenic and metals to Commencement Bay. There have also been many documented releases of fuels that have contributed to the PAH contamination now observed in sediments of the Ruston-Pt. Defiance Shoreline. Transformers containing PCBs have been used on the ASARCO property. While there have been no documented spills from these transformers, the spatial gradient of PCB contamination in the bay sediments suggests that releases have occurred. Tacoma City Light maintains an electrical substation near the ASARCO property. Any past spills from this facility could also potentially be responsible for the contamination of bay sediments observed, particularly near the ASARCO north outfall.

Although ASARCO is the major source of contaminants to the problem area, for most of the contaminants it is difficult to determine if the major input has occurred through any one route. There are several routes by which contaminants may migrate from the ASARCO property into the bay:

- Outfalls - There are four outfalls which serve the ASARCO property, three of which are NPDES-permitted. Their effluents originate from a variety of sources, including stormwater runoff, groundwater seepage, noncontact cooling water, contact cooling water (pre-1976), and spills. The three discharges that have been sampled have all been found to be major sources of arsenic and metals.

- Groundwater - Much of the ASARCO property has been created by the dumping of molten slag into Commencement Bay. Movement of groundwater through this slag, promoted by tidal action, may be a significant source of arsenic and metals to the bay. Chronic discharge of acidic wastewater may have enhanced leaching of metals from the slag. The historical practice of spreading out molten slag on the ground surface and irrigating it to promote cooling may also have contributed to arsenic and metal contamination via groundwater.

- Atmospheric Emissions - In-plant emissions may contribute to stormwater runoff or groundwater contamination.

With the recent closure of the copper smelting operations at ASARCO, a decrease in contaminant release can be expected, particularly in atmospheric emissions. However, groundwater and discharge of storm water and/or cooling water through the four outfalls can be expected to continue, introducing contaminants to the bay for many years to come.

3.4.6 Sitcum Waterway

The Sitcum Waterway source evaluations were conducted on six contaminants or contaminant groups. Four sources of copper, lead, zinc, and arsenic to Sitcum Waterway have been identified, all of which are ongoing:

- The North Corner storm drain (SI-172) is the major source of arsenic to the Sitcum Waterway, contributing 93 percent of the total quantified loading. It is also a significant source of copper, lead, and zinc.

- The elevated metal concentrations along the north shore are believed to be a result of ore spillage from the Port of Tacoma ore docks. Copper, lead, and zinc ores are off-loaded at the facility and spillage is traditionally washed into the waterway.

- Drain SI-717, which discharges along the north shore near the head of the waterway, is a source of copper, lead, and zinc. The sources of metals to this drain have not been determined, but may be associated with the Port's ore handling facilities.

- Drain SI-176, which discharges on the south shore of the waterway, is a source of copper, lead, and zinc. The source of metals to this drain is unknown.

No definite sources could be identified for aromatic hydrocarbons and dibenzofurans. The area of highest concentrations near the waterway mouth may have been caused by exposure by dredging of historically contaminated sediments.

3.5 POTENTIAL REMEDIAL TECHNOLOGIES

Eleven problem areas in five waterways and along the Ruston-Pt. Defiance Shoreline have been recommended for evaluation of potential remedial action. Potential sources and corresponding problem contaminants associated with each source are summarized in Table 10 for each problem area. Classifications of potential source control remedial technologies (i.e., direct waste discharge controls, surface water controls) are identified for each potential source. Specific source control technologies and their applicability to each problem area are identified in detail as part of the Commencement Bay Remedial Investigation (Task 6).

In general, there are three basic sediment management technologies: removal (dredging), capping, and in situ treatment. In no case is sediment remedial action recommended until the sources of contamination are effectively controlled.

Dredging methods are classified as mechanical, hydraulic, or pneumatic. As part of the Commencement Bay Remedial Investigation the U.S. Army Corps of Engineers prepared an evaluation of alternative dredging methods and equipment. According to their evaluation, hydraulic dredging is the most efficient method for removing sediments contaminated with particle-bound or soluble contaminants, and mechanical dredging is the most efficient method for removing sediments contaminated with volatile contaminants.

Capping and in situ treatment may have limited applicability within the Commencement Bay waterways due to the frequent dredging activities required to maintain adequate water depths for deep draft shipping vessels. In addition, most in situ treatment/ stabilization methods are new or emerging technologies whose effectiveness may be unproven. The National Contingency Plan (NCP) criteria encourage the evaluation of these innovative or advanced technologies. However, there must be some degree of certainty regarding the effectiveness of these technologies or they will likely be eliminated by the criteria established for the initial screening process. The feasibility of dredging, capping, and in situ technologies will be evaluated in the Commencement Bay Nearshore/Tideflats Feasibility Study.

TABLE 10. SUMMARY OF POTENTIAL CONTAMINANT SOURCES, PROBLEM CONTAMINANTS, POTENTIAL REMEDIAL TECHNOLOGIES, AND DATA NEEDS FOR THE TEN PRIORITY PROBLEM AREAS IN COMMENCEMENT BAY

Segment Containing Problem Area[a] and Potential Sources	Potential Source Control Remedial Technologies	Potential Problem Contaminants[b]	Data Needs
• Ruston-Pt. Defiance Shoreline, Segment 2 - ASARCO	Direct waste discharge controls Atmospheric release controls Surface water controls Contaminated soils management[f] Surface water treatment Groundwater controls[f] Groundwater treatment[f]	Priority 1: Hg, As, LPAH Priority 2: HPAH, PCBs, Cd, Ni, Cu, Zn, Pb, Sb [dibenzofuran][c] Priority 3: dichlorobenzenes, N-nitrosodiphenylamine, 2-methylphenol, 4-methylphenol, phthalate esters, [1-methyl-(2-methylethyl)-benzene, biphenyl, dibenzothiophene, methylphenanthrenes, retene, methylpyrenes][c]	Additional source identification for problem chemicals with unknown sources Priority 1: LPAH Priority 2: HPAH, PCBs [dibenzofuran][c] Priority 3: dichlorobenzenes, N-nitrosodiphenylamine, 2-methylphenol, 4-methylphenol, phthalate esters, [1-methyl (2-methylethyl)benzene, biphenyl, dibenzothiophene, methylphenanthrenes, retene, and methylpyrenes][c] Define contaminant transport mechanisms and quantify relative loadings from ASARCO Determine leachability of metals in slag Determine vertical extent of contamination
• St. Paul Waterway - Champion International	Direct waste discharge controls Surface water controls[f] Surface water treatment[f]	Priority 1:4-methylphenol Priority 2:[benzyl alcohol, 1-methyl-(2-methylethyl)benzene, 2-methoxyphenol][c] Priority 3:Ni, LPAH, 2-methylphenol, phenol [biphenyl, diterpenoid hydrocarbons, retene, TVS, TOC][c]	Additional characterization of effluent from Champion International for problem chemicals and their precursers Priority 1: 4-methylphenol Priority 2: [benzyl alcohol, 1-methyl(2-methylethyl)benzene, 2-methoxyphenol][c] Priority 3: Ni, LPAH, 2-methylphenol, phenol, [biphenyl, diterpenoid hydrocarbons, retene][c] Determine spatial and vertical extent of contamination Determine potential recovery rate for contaminants in problem area

Table 10. (Continued)

• City Waterway Segment 1		Priority 1: Hg, Zn, Pb [TOC[d]][c] Priority 2: HPAH, Cd, Ni, Cu, LPAH, 2-methylphenol, 4-methylphenol, phthalate esters [oil & grease][c] Priority 3: dichlorobenzenes, N-nitrosodiphenylamine, [aniline, benzyl alcohol][c]	Additional source identification for problem chemicals with unknown sources Priority 2: HPAH, LPAH, 2-methylphenol, 4-methylphenol, phthalate esters Priority 3: dichlorobenzenes, N-nitrosodiphenylamine, [analine, benzyl alcohol][c] Source identification within drainage areas Determine potential for Wheeler-Osgood as a source of contaminants to City Waterway Determine sedimentation rate Determine vertical extent of contamination Conduct storm and sanitary sewer surveys to identify cross connections and unauthorized connections Investigate potential sources of gasoline and oil observed at the Tacoma Spur site, West Coast Grocery, and 15th Street
- Storm drains CN-237, CS-237, and CI-230	Direct waste discharge controls Surface water controls Storm sewer inspection and maintenance Stormwater treatment Discharge to POTW		
- Martinac Shipbuilding[c]	Direct waste discharge controls Atmospheric release controls Surface water controls Surface water treatment		
- American Plating	Direct waste discharge controls Contaminated soils management Groundwater controls[f]		
• Hylebos Waterway Segment 5		Priority 1: PCBs Priority 2: HCBD, chlorinated benzenes, chlorinated ethenes, Pb [pentachlorocyclopentane isomer][c] Priority 3: Hg, HPAH[e], Cu[e], Zn[e], LPAH[e], phenol [benzyl alcohol, biphenyl][c]	Additional source identification for problem chemicals with unknown sources Priority 1: PCBs Priority 2: HCBD, chlorinated benzenes, chlorinated ethenes, Pb, [pentachlorocyclopentane isomer][c] Priority 3: Hg, HPAH[e], Cu[e], Zn[e], LPAH[e], phenol, [benzyl alcohol, biphenyl][c] Determine vertical extent of contamination Industrial/commercial source investigation for PCBs
- Occidental Chemical Corp.	Direct waste discharge controls Surface water controls Surface water treatment Contaminated soils management Groundwater controls Groundwater treatment		
• Sitcum Waterway		Priority 1: none Priority 2: As[e], Cu[e], Zn, Pb Priority 3: N-nitrosodiphenylamine [dibenzofuran, 1-methyl-(2-methylethyl)benzene, diterpenoid hydrocarbons][c], LPAH, HPAH	Additional source identification for problem contaminants with unknown sources Priority 3: N-nitrosodiphenylamine, [dibenzofuran, 1-methyl (2-methylethyl)benzene, diterpenoid hydrocarbons][c] LPAH, HPAH Source identification within drainage areas Determine vertical extent of contamination
- Port of Tacoma's Terminal 7, ore unloading facilities	Direct waste discharge controls Atmospheric release controls Surface water controls Surface water treatment		
- Storm drains SI-172 SI-176 SI-717	Improve materials handling within drainage areas Surface water controls Surface water treatment Storm sewer inspection and maintenance Discharge to POTW		

TABLE 10. (Continued)

• Hylebos Waterway Segment 1			
- Log sort yard, (unpaved that used ASARCO slag as ballast)	Surface water controls Surface water treatment Contaminated soils management[f] Groundwater controls[f] Groundwater treatment[f]	Priority 1: HPAH, As, Zn (limited evidence of a gradient for each with one or more toxicity/effects indicator) Priority 2: phenol, Sb Priority 3: phthalate esters, ethylbenzene, tetrachloroethene, [xylenes, 1-methyl-(2-methylethyl)-benzene, methylpyrenes, TVS][c]	Additional source identification for problem chemicals with unknown sources Priority 1: HPAH Priority 2: phenol Priority 3: phthalate esters, ethylbenzene, tetrachloroethene, [xylenes, 1-methyl(2-methylethyl) benzene, methylpyrenes][c]
- Hylebos Creek	Surface water controls Surface water treatment Contaminated soils and landfilled materials management		Source identification within drainage areas Determine vertical extent of contamination
- Kaiser Ditch	Direct waste discharge Surface water controls Surface water treatment Contaminated soils management		Conduct industrial/commercial source investigations for PCBs Additional sediment sampling for PCBs to determine temporal trends and gradients Investigate ongoing release of PAHs from Kaiser Ditch
• Hylebos Waterway Segment 2			
- Pennwalt Chemical Corp.	Direct waste discharge controls Surface water controls Surface water treatment Contaminated soils management Groundwater controls Groundwater treatment	Priority 1: PCBs Priority 2: HPAH, Ni, As, tetrachloroethene [Hg[e], Cu[e], Zn[e], Pb[e] (intertidal sediments only)] Priority 3: HCBD, chlorinated benzenes, phthalate esters, phenol [benzyl alcohol, dibenzothiophene, methylphenanthrenes, methylpyrenes][c]	Additional source identification for problem chemicals with unknown sources Priority 1: PCBs Priority 2: HPAH, Ni, [Hg[e], Cu[e], Zn[e], Pb[e]] Priority 3: HCBD, chlorinated benzenes, phthalate esters, phenol, [benzyl alcohol, dibenzothiophene, methylphenanthrenes, methylpyrenes][c]
- Morningside Ditch	Direct waste discharge controls[f] Surface water controls Surface water treatment Contaminated soils[f]		Source identification within drainage area Determine vertical extent of contamination Addition sediment sampling for PCBs to determine temporal trends and gradients Conduct industrial/commercial source investigation for PCBs
• City Waterway Segment 2 (Wheeler-Osgood)			
- Storm drain CW-254	Surface water controls Surface water treatment Storm sewer inspection and repair Groundwater controls[f] Groundwater treatment[f] Discharge to POTW	Priority 1: none Priority 2: HPAH, Cd, Cu[e], Zn, dichlorobenzenes, LPAH[e], Pb, N-nitrosodiphenylamine, 4-methylphenol, phenol [biphenyl, TVS, TOC, oil & grease][c]	Additional source identification for problem chemicals with unknown sources Priority 2: HPAH, Cd, Cu[e], Zn, dichlorobenzenes, LPAH, Pb, N-nitrosodiphenylamine, 4-methylphenol, phenol, [biphenyl][c] Determine sedimentation rate Determine vertical extent of contamination Conduct storm and sanitary sewer surveys to identify cross connections and unauthorized connections Investigate groundwater from the Tar Pits as a source of methylphenols to Wheeler-Osgood Additional sampling to establish contaminant gradients within the waterway

TABLE 10. (Continued)

• Middle Waterway - Maritime Industries (Foss Launch and Tug, Marine Industries Northwest, Cooks Marine Specialties)	Direct waste discharge controls Atmospheric release controls[f]	Priority 1: none Priority 2: Hg, Cu Priority 3: HPAH, As, Zn, dichlorobenzenes, LPAH, pentachlorophenol, Pb, 4-methylphenol, phenol [dibenzothiophene, diterpenoid hydrocarbons, methylpyrenes][c]	Additional source identification for those chemicals with unknown sources Priority 2: Hg, Cu Priority 3: HPAH, As, Zn, dichlorobenzenes, LPAH, pentachlorophenol, Pb, 4-methylphenol, phenol, [dibenzothiophene, diterpenoid hydrocarbons, methylpyrenes][c] Additional sediment sampling to define spatial extent and contaminant gradients Determine vertical extent of contamination Characterize storm water from drains at the head of the waterway Investigate the release of contaminants by the maritime industries along Middle Waterway Investigate wood products industries (Champion International, Coast Craft, Paxport) as potential sources of wood wastes and wood treating wastes
• Ruston-Pt. Defiance Shoreline Segment 3 - ASARCO (slag in sediment)	Stabilize or remove slag along shore	Priority 1: none Priority 2: As, Cd, Cu, Zn, Pb, N-nitrosodiphenylamine, Sb Priority 3: none	Additional source identification for those chemicals with unknown sources Priority 2: N-nitrosodiphenylamine Determine vertical extent of contamination Analyze sediments off ASARCO for N,N-dimethylaniline (DMA); review tentatively identified compounds in past samples for DMA
• City Waterway Segment 3 - "D" Street Petroleum storage facilities	Improved product handling Inspection of storage and distribution system, and implementation of appropriate corrective measures Groundwater controls Groundwater treatment	Priority 1: none Priority 2: HPAH, LPAH Priority 3: PCBs[e], Zn[e], phenol [biphenyl, dibenzothiophene][c]	Additional source identification for those chemicals with unknown sources Priority 2: HPAH, LPAH Priority 3: PCBs[e], Zn[e], phenol, [biphenyl, dibenzothiophene][c] Determine vertical extent of contamination Identify sources and transport mechanisms for PAH

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[a] Problem areas encompass all stations sampled in 1984 only in Segments HYS1, SIS1, CIS2, RSS2, RSS3, and possibly MDS1 (Station MD-12 in this segment was close to apparent effect thresholds for several chemicals).

[b] Concentrations of these chemicals exceeded an apparent effect threshold (by various normalizations) in sediment from at least one station in the defined problem area. Chemicals are listed in each priority group in descending order of their calculated toxicity significance factor, if available. Stations with and without biological data area included. Priority 1 chemicals showed a concentration gradient with toxicity or biological effects gradients. Priority 2 chemicals were above apparent effect thresholds at more than one station within the problem area, but either no gradient corresponding to that for toxicity/effects was observed, or no biological data were available to assess gradients. Priority 3 chemicals were above apparent effect thresholds at one station only within the problem area.

[c] Toxicity significant factors were not available for the chemicals listed in brackets. These chemicals have not been prioritized relative to other chemicals in the same priority group.

[d] TOC concentrations did not exceed an AET in the problem area defined in Segment CIS1 but the TOC concentration gradient corresponded with observed changes in effects (e.g., sediment toxicity). This correspondence may result from the covarying distribution of TOC with other contaminants, including lead and zinc.

[e] Chemical elevated above an AET in the defined problem area only on the basis of historical data.

[f] May not be applicable, additional evaluation is necessary to confirm.

4. RECOMMENDATIONS OF AREAS AND SOURCES FOR POTENTIAL REMEDIAL ACTIONS

4.1 INTRODUCTION

The final prioritization of problem areas for potential remedial actions is presented in this section. Recommendations of areas and sources for these remedial actions are based on evaluations of:

- The environmental hazard indicated by the problem area contamination, toxicity, and biological effects
- The spatial extent of each problem area
- The confidence that sources of potential problem chemicals in each problem area have been accurately identified.

A prioritization of the 21 problem areas and all identified problem chemicals was made in Section 3.3. Eight problem areas were given the highest priority for source evaluation. Four problem areas were given the next highest priority for source evaluation. The remaining nine problem areas were not included for priority source evaluation because of their relatively low environmental hazard ranking. The spatial extent of each problem area was also defined in Section 3.3, but was not considered in the development of recommendations of problem areas for source identification. In this section, the relative spatial extent of each problem area is considered, along with the magnitude of contamination, toxicity, and biological effects. For example, large areas with a high degree of environmental hazard are ranked higher than are isolated hot spots posing a similar hazard. Source evaluations for each problem area are also rated according to the level of confidence that the problem sources have been accurately identified. Thus, the highest ranking problem area for potential remedial action is large, poses a substantial environmental hazard, and has well-characterized sources. In this ranking method, a small "hot spot" exhibiting substantial effects that have been traced confidently to a contaminant source may be ranked at the same, or even higher, priority than a much larger problem area with unknown sources. To allocate resources efficiently, "hot spots" with known sources would be recommended for potential remedial action before the larger area with unknown sources.

Potential remedial actions include source control and/or sediment remedial action (see Tetra Tech 1984a). Potential remedial technologies have been discussed in Section 3.5.

A final prioritization of Commencement Bay problem areas is presented in Table 11. Scores for each problem area in three categories (environmental significance, spatial extent, and confidence of source identification) were summed to estimate the relative priority for potential remedial action. Environmental significance was scored from 1 to 4 according to the magnitude of observed contamination, toxicity, and biological effects. The eight

TABLE 11. FINAL RANKING OF PROBLEM AREAS

Segment Containing Problem Area[a]	Environmental Significance	Spatial Extent	Confidence of Source Identification	Total Score
RSS2	4	4	4	12
SPS1	4	3	4	11
CIS1	4	3	4	11
HYS5	4	3	4	11
SIS1	4	4	3	11
HYS1	4	4	3	11
HYS2	4	2	4	10
CIS2	4	1	3	8
MDS1	3	3	2	8
RSS3	1	3	4	8
CIS3	3	2	2	7
				[b]
HYS4	3	2	1	6
RSS1a (RS-13)	3	1	1	5
BLS2	2	1	1	4
MIS1	2	1	1	4
RSS1b (RS-15)	1	1	1	3
HYS3	1	1	1	3
BLS1	1	1	1	3
HYS6	1	1	1	3
BLS3	1	1	1	3
BLS4	1	1	1	3

[a] Problem areas did not always encompass an entire segment. Problem areas in the segments indicated are listed in order of their total score for environmental significance, spatial extent, and confidence of source identification.

[b] Identification of potential remedial technologies was conducted for problem areas with a total score greater than or equal to 7.

highest-priority areas identified in Section 3.3 were given a score of 4 for environmental significance. The four second-priority sites (Section 3.3) were given a score of 3, and the two third-priority sites (plus Milwaukee Waterway) were given a score of 2. All remaining lower-priority problem areas were given scores of 1.

The spatial extent (surface sediments only) of each problem area was estimated by planimetry. Scores were assigned on the basis of size of each problem area as follows:

- >50 acres; score = 4
- 30-50 acres; score = 3
- 10-30 acres; score = 2
- <10 acres; score = 1.

The confidence of source identification was scored according to the following qualitative criteria:

- Ongoing sources were well-identified by spatial patterns of contamination (and effects), and chemical characteristics of the sources matched chemical characteristics of the receiving water environment; score=4. Or, contamination was clearly established as historical, although sources may not have been well-identified; score=4
- Potential sources were identified, but their relative contributions compared with historical deposits were not clear; score=3
- Adjacent sources were suggested by land use or drainage patterns, but spatial patterns of contamination were ambiguous; score=2
- Source unidentified; score=1.

All problem areas with clearly identified sources (i.e., score=4) exhibited major environmental effects, with the exception of the problem area within Segment RSS3 on the Ruston-Pt. Defiance Shoreline, where the source of metals contamination is believed to be ASARCO slag or ores in the sediments. No benthic data directly comparable to those in other areas (i.e., 0.06-m^2 grab samples) were collected from this problem area because of sampling difficulties. Qualitative evaluation of replicate 0.1-m^2 grab samples indicated a general similarity to Carr Inlet reference conditions. The differences in numbers of species and abundances of the major taxonomic groups were not large, and probably reflected natural differences in benthic community structure between the Segment RSS3 site and Carr Inlet. Therefore, major impacts to benthic communities did not appear to be occurring in the potential problem area. Based on this qualitative analysis, the score for environmental significance was reduced from 2 to 1 (Table 11). This area will still be evaluated for potential remedial action.

All of the problem areas in Table 11 with a total score ≤6 have a low priority for evaluation of potential remedial action. These ten problem areas had largely unidentified sources and were not extensive. Potential "hot spots" in Segments HYS4 (Hylebos Waterway) and RSS1 (Station RS-13; Ruston-Pt. Defiance Shoreline) are included in this group. Ship scour or some unidentified activity could have resulted in the multiple significant benthic depressions observed at a single station (HY-37) in the Segment HYS4 hot spot. Further characterization of potential contaminant sources is required for the Station RS-13 hot spot within Segment RSS1. Further source identification of problem chemicals is recommended for each of these low priority problem areas before the feasibility of any remedial action is evaluated.

Recommendations for the remaining problem areas with scores ≥7 in Table 11 are presented below.

4.2 RECOMMENDATIONS FOR POTENTIAL REMEDIAL ACTION

Potential remedial actions include source control and sediment actions such as removal, capping, or in situ treatment. All problem areas discussed below have ongoing, potentially ongoing, or unknown sources of problem chemicals. Remedial action with respect to the contaminated sediments is recommended for all areas only after the sources have been identified and effectively controlled.

4.2.1 Hylebos Waterway

Hylebos Problem Area In Segment HYS1--

Potential sources of HPAH, arsenic, copper, lead, and zinc were identified for the problem area in Segment HYS1 of Hylebos Waterway. Source control measures are recommended to reduce HPAH discharge from Kaiser Ditch. Source control evaluation is also recommended to reduce metals discharge (especially arsenic and zinc) from unpaved log sort yards (Wasser Winter, Cascade Timber yard #2, Dunlap Towing, Louisiana Pacific), and from Hylebos Creek (B&L Landfill and Fife Ditch).

Hylebos Problem Area In Segment HYS2--

PCBs were the highest priority chemicals found in the problem area defined within Hylebos Segment HYS2. Exposure of historical accumulations of PCBs [and other chemicals (e.g., hexachlorobutadiene)] by dredging was identified as the most probable source of this contamination. There was little evidence of an ongoing source of PCBs in this area. A PCB source reconnaissance survey is recommended prior to evaluation of sediment remedial action. Potential source control should also be evaluated for other problem chemicals discussed below that have significant ongoing sources in this problem area. The extent of subsurface PCB contamination was not well characterized, but is probably broad. This problem should be considered when dredging projects are planned in Hylebos Waterway.

Elevated HPAH concentrations were found in subtidal sediments of the problem area in Segment HYS2 near the boundary between Segments HYS1 and HYS2. These sediments do not appear to be within the dredged area discussed for PCBs. The HPAH contamination is likely an extension of the contamination found in the problem area within Segment HYS1. As discussed previously, source control evaluation for HPAH has been recommended for the Kaiser Ditch, the major HPAH source to Hylebos Waterway.

Pennwalt Chemical Corporation was identified as an ongoing source of chlorinated ethenes, chlorinated butadienes, arsenic, copper, lead, and zinc to intertidal sediments of the Segment HYS2 problem area. Tetrachloroethene is also elevated in some of the subtidal sediments. Source control evaluation is recommended for these chemicals in the main plant outfall, surface drains, groundwater seeps, and groundwater in shallow and intermediate aquifers.

Hylebos Problem Area In Segment HYS5--

Source control evaluation for chlorinated compounds, including chlorinated ethenes and chlorinated butadienes, from Occidental Chemical Co. is recommended. Although chlorinated butadienes (with the exception of hexachlorobutadiene) did not exceed apparent effect thresholds for sediment toxicity or benthic community structure, source control for these substances is still recommended for the Occidental Chemical Co. main outfall based on their extreme concentrations in this area. Very high concentrations of chlorinated ethenes in this area were restricted to the immediate vicinity of the Occidental Chemical Co. docks. Because of the localized nature of this contamination, clear response gradients could not be established. However, because of the magnitude of chlorinated ethene contamination, these substances warrant a high priority for source control. The source of PCB contamination in this area was not established. A PCB reconnaissance in this area is recommended. PCB contamination in this area should be considered when dredging is planned.

4.2.2 Sitcum Waterway

Ore unloading operations at the Port of Tacoma docks are a potential source of metals contamination to the north shore of the waterway. Although the contribution of this source to overall sediment metals contamination cannot be established with available data, it is recommended that evaluations be conducted on possible control technologies for minimizing release of ore into the waterway.

Three storm drains (i.e., SI-172, SI-176, SI-717) are also major contributors of metals to Sitcum Waterway. Source identification within the drainage areas of these storm drains is necessary before source controls can be implemented.

4.2.3 St. Paul Waterway

The main outfall from the Champion International pulp mill located at the mouth of St. Paul Waterway, is an ongoing source of alkylated phenols (or their precursors), methoxyphenols, copper, organic enrichment, and chloroform. Source control evaluation for alkylated phenols (or their precursors) is recommended at Champion International pulp mill. Source control for copper and chloroform is also recommended because these contaminants were measured at elevated concentrations in plant effluent or, in the case of copper, exceeded applicable water quality criteria.

4.2.4 Middle Waterway

Ship repair operations were identified as potential sources of mercury and copper in Middle Waterway. No definite sources of pentachlorophenol, dichlorobenzenes, and PAH have been identified. Evaluation of source control at the ship repair operations is recommended. Source investigations for pentachlorophenol, dichlorobenzenes, and PAH are recommended before evaluating source controls.

4.2.5 City Waterway

City Problem Area In Segment CIS1--

The south Tacoma and Nalley Valley drains (CS-237 and CN-237) at the head of City Waterway are the largest ongoing sources of metals (especially lead) and organic material. The specific sources of metals and organic matter within these drainage areas have not been identified. Therefore, source investigations are recommended within these drainage areas. Source control alternatives should be evaluated following identification of specific sources. Source investigations and source control evaluations should also be conducted for the 15th Street drain, which also contributes metals and PAH to the waterway. Source control evaluation is recommended for Martinac Shipbuilding, which is a probable source of copper and zinc to City Waterway. The wood products industries, the Tar Pits site, and the 23rd and A Street coal gasification site are possible sources of 4-methylphenol to City Waterway. The contributions of 4-methylphenol from these sources should be investigated.

City Problem Area In Segment CIS2--

Ongoing sources of the contaminants of concern in Wheeler-Osgood Waterway could not be identified. Source investigations are therefore recommended for 4-methylphenol, 1,2-dichlorobenzene, organic material, lead, and zinc. Source investigations should include evaluation of specific sources of these contaminants within the drainage area served by CW-254. The potential for groundwater transport of 4-methylphenol from the Tar Pits site also requires further investigation.

City Problem Area In Segment CIS3--

Sources of the problem contaminants in City Waterway Segment 3, including LPAH and HPAH, could not be identified with existing information. Therefore, remedial action for this problem area is not recommended until contaminant sources and transport mechanisms have been established. Further source investigation is recommended for PAH.

4.2.6 Ruston-Pt. Defiance Shoreline

The ASARCO facility was identified as the source of metals (including high-priority mercury and arsenic) and PAH to the adjacent problem area. Although ASARCO is the major source of contaminants to the problem area, for most of the contaminants it is difficult to determine if the major loading has occurred through any one route (i.e., process effluent, surface water runoff, groundwater). Because the facility has closed recently, a characterization and source control evaluation of the residual discharge of contaminants from site runoff and groundwater is recommended. A reconnaissance survey is recommended to determine possible sources of PCBs to this problem area.

4.3 GENERAL RECOMMENDATIONS

There were several PCB hot spots in the project area where PCBs concentrations exceeded apparent effects thresholds. In addition, general PCB contamination within the waterways is sufficient to be the apparent cause of elevated PCBs in fish muscle, fish liver, and crab muscle tissue. PCBs are the chemicals that are responsible for the highest predicted risk to human health from fish consumption. The sources of PCBs are unknown. A general reconnaissance survey of the area for PCB sources is recommended. Other chemicals for which general reconnaissance surveys are recommended include aromatic hydrocarbons and dibenzofuran.

5. OVERVIEW OF CONTAMINATION AND BIOLOGICAL EFFECTS IN COMMENCEMENT BAY

The Commencement Bay Nearshore/Tideflats Remedial Investigation included a comprehensive assessment of sediment contamination and associated biological effects. Results of this assessment were used to identify and prioritize problem areas. An overview of these conditions in Commencement Bay is provided in this section.

During this and previous studies, several hundred chemicals have been tentatively identified in Commencement Bay sediment samples. Routine analyses have been conducted for about 150 chemical variables. Chemicals detected in over two-thirds of the surface sediments analyzed in the Superfund study included phenol, 4-methylphenol, PAH, 1,4-dichlorobenzene, PCBs, dibenzofuran, and most U.S. EPA priority pollutant metals. Most of these chemicals had already been reported in many areas of Commencement Bay. Chemicals detected only rarely or not at all in the present study included pesticides, most organonitrogen compounds, most chloro- and nitrophenols, halogenated ethers, 2,3,7,8-dibenzodioxin (never detected), selenium, and thallium. High concentrations of some of the pesticides in this group had been found in past studies, but the findings had not been confirmed by mass spectroscopy.

Sediment contamination throughout the Commencement Bay study area is variable both in concentration and composition. The highest PAH concentrations were found near the head of Hylebos Waterway. Benzo(a)pyrene was found at over 1,000 times reference conditions at one Hylebos Waterway station. In this study and in others, Hylebos Waterway sediments contained a complex mixture of chlorinated compounds, many of which were unidentified. Tri- and tetrachlorinated butadienes were found at well over 1,000 times reference conditions near the mouth of the waterway. Other chemicals measured at over 1,000 times reference concentrations were 4-methylphenol and 2-methoxyphenol (guaiacol) in sediments adjacent to the main outfall of the Champion International pulp and paper mill in St. Paul Waterway, and four metals (antimony, arsenic, copper, and mercury) in sediments adjacent to the main outfalls of the now closed ASARCO copper smelter on the Ruston-Pt. Defiance Shoreline. With some exceptions, concentrations of most chemicals measured in the current investigation of subtidal sediments were comparable to or higher than those in subtidal and intertidal sediments collected in previous studies. Chlorinated ethene concentrations in intertidal sediments from Hylebos Waterway were higher in other studies than those in subtidal sediments in the present study. Metal concentrations in sediments near drains at the head of Sitcum Waterway were also higher in other studies.

In the present study, Blair and Milwaukee Waterways contained the least contaminated subtidal sediments. Additional sampling was not conducted in the Puyallup River, but historical sediment concentrations were low. The most extreme contamination in the remaining areas was typically located in small areas near point source discharges. Pronounced gradients in chemical concentrations were observed in several waterways (e.g., Hylebos, St. Paul, and City Waterways) and along the Ruston-Pt. Defiance Shoreline. Concentrations of contaminants in sediments collected well outside of Hylebos and Blair Waterways were low, approaching reference conditions in most cases.

For most substances, the range of concentrations was greater in subsurface sediments than in surface sediments. The depth of penetration in the sediments was often limited by textural characteristics. Concentrations approaching reference area conditions for all chemicals were reached at the bottom of only some cores. Many chemicals present at elevated concentration at depth in cores were still below apparent effect thresholds for toxicity and benthic effects. Consistently low concentrations of chemicals were reached at the bottom of all cores collected in a special drilling program in Blair Waterway.

Studies of benthic macroinvertebrate assemblages and laboratory bioassays of sediments were used as site-specific indicators of biological effects and toxicity in Commencement Bay. These studies demonstrated that areas of high toxicity and effects on benthos were generally isolated near known pollutant sources. The most severe effects were observed at single sampling stations near two industrial facilities: Champion International pulp mill and the ASARCO smelter. In these areas of extreme adverse effects, very few animals lived in the sediments or survived a 10-day laboratory exposure to the sediments. These areas were also characterized by very high sediment contamination in which concentrations of several chemicals were over 1,000 times higher than reference concentrations. In these two areas, there was noticeable improvement in benthic conditions at the next closest transect stations (250-400 ft away), indicating that the areas of maximum effects were of limited spatial extent. Biological conditions varied considerably from station to station in the waterways. For example, in Hylebos Waterway, areas of high toxicity and altered benthic communities were interspersed among areas of low toxicity and benthic effects. Some waterways displayed well-defined areas of high toxicity and benthic effects (e.g., Hylebos and City Waterways) and others displayed little evidence of such effects (e.g., Milwaukee and Middle Waterways).

In general, the waterway sediments supported higher abundances of benthic macroinvertebrates than were found in Carr Inlet or along the Ruston-Pt. Defiance Shoreline. The waterway sediments supported fewer species than other areas sampled, indicating possible generalized effects from contamination, sediment disturbance, or presence of fine-grained sediments. Typical benthic assemblages in the waterways were dominated by polychaete worms and small clams. These organisms are important food items for many bottom-feeding fishes.

Demersal fish assemblages in the waterways were dominated by flatfishes such as English sole. Fish assemblages in the waterways were over twice as abundant as those in Carr Inlet. These fishes may be attracted by the abundant food resources in the waterways or by the increased habitat complexity in the harbor environment. English sole in several waterways had significantly elevated prevalences of one or more liver lesions. The highest overall lesion prevalence was measured in Middle Waterway, where 40 percent of English sole sampled had one or more serious lesions. The causes of these lesions are unknown, but the lesions are similar to those induced in laboratory animals exposed to toxic chemicals. The effects of these lesions on the fish are also unknown. In this study, however, fish with serious liver lesions did not exhibit reduced condition (as expressed by weight at a given length) when compared to fish without lesions.

Although many chemicals were highly elevated in Commencement Bay sediments, relatively few were detected in the tissues of English sole and crabs. The only metals that were accumulated above reference levels were copper in English sole and lead and mercury in crabs. PCBs were the most consistently detected organic compounds and were measured at concentrations about 10 times reference levels in Hylebos and City Waterways. In the heavily fished Pt. Defiance area, concentrations of PCBs in English sole were close to reference levels.

In summary, the Commencement Bay study area presents a mixed picture relative to contamination and biological effects. The bay is not an ecological disaster area with overall high contamination and pervasive biological effects. Commencement Bay is a complex estuarine environment in which the levels of contamination and effects vary considerably. While there are definite indications of stress to local biological communities (e.g., altered benthic assemblages, accumulation of contaminants in fish and shellfish, and liver lesions in flatfish), most of the area is characterized by high abundances of benthic organisms and demersal fishes, and the fish do not appear to be severely stressed by liver lesions or accumulations of toxic substances.

6. STUDY DESIGN EVALUATION AND RECOMMENDATIONS FOR FUTURE STUDIES

The Commencment Bay Nearshore/Tideflats Remedial Investigation involved the collection of extensive data and the implementation of a complex decision-making process. Because of the unique nature of the study area and the complexity of potential sources, contaminants, and biological effects, many of the investigative techniques and decision criteria were developed specifically for this project. This section provides a retrospective evaluation of the innovative study approach and presents recommendations for future studies of sediment contamination in the marine environment.

6.1 SEDIMENT CHEMISTRY

1. The addition of multiple (>50) isotopically labeled recovery standards to every sample increased confidence in the validity of detection limits for undetected target compounds. By forcing a search for each recovery standard, this recovery technique also increased the efficiency and reporting of target compounds that otherwise may have been overlooked in the complex extracts.

2. Use of a defined list of tentatively identified compounds to search for in each sample analyzed greatly improved the value of these data in spatial characterizations of contamination.

3. Low detection limits for organic compounds in the range of 5 to 50 ppb (dry weight sediment or wet weight tissue) were useful in defining conditions in the reference area, extent of problem areas, and interrelationships among chemical and biological indicators, and in estimating human health risks. Because major sample interferences were removed to attain these limits, improved precision was possible in the quantification of compounds present at high concentration.

4. Historical problems with potential misidentification of pesticides in sediments was successfully avoided by using mass spectroscopy instead of electron capture detection. This advantage outweighed the increase in detection limits by mass spectroscopy, but electron capture analyses are still recommended for tissue samples (with mass spectral confirmation of any high values) to obtain low enough detection limits for use in health risk assessments.

5. Sampling of suspended solids in the water column for toxic chemicals at two depths and at two times during the study made possible only a limited qualitative estimate of the ambient levels or apparent transport of chemicals. Even

with filtering 100 L of water, detection limits for most organic compounds other than PAH were too high to be useful. Water column studies are recommended only for metals, PAH (by GC/MS), or selected chlorinated compounds amenable to sensitive GC/ECD analysis. The organic analyses should be conducted with a minimum of 0.5 g of material.

6. PCB concentrations reported as total PCBs enabled an adequate characterization of the PCB distribution. This reporting format is recommended because PCB mixtures in the environment are rarely representative of original Aroclor components.

7. A two-phase coring program is recommended to determine the extent of contamination in historical sediments and to overcome penetration problems caused by textural characteristics of the sediments. The first phase (lower cost) should use a coring device (box, Kasten, wide-diameter gravity core) that can recover intact surface and near-surface sediments; the second phase (higher cost) should incorporate drilling techniques to recover deeper sediments if analysis of the bottom of the phase I core shows elevated contamination.

8. A sampling interval of up to 1 ft in sediment cores was adequate when the primary goal was focused on potential required dredging depths for contaminated sediments. However, the bottom 2 cm of each core should be analyzed in future studies of this type to reduce uncertainty as to whether a significant decline in concentration toward the bottom of the core was masked by compositing over large depth intervals.

9. Sampling intervals of 1-5 cm thickness should be used in sediment cores to estimate the chronology of deposition. This chronology can be critical in determining whether contamination is historical or ongoing.

10. Substantial quality assurance review and laboratory oversight were required in a study of this complexity. This review and oversight were based on an integration of analytical chemistry techniques with environmental trend analysis. Such an integration should be required in future studies and should always include a laboratory site visit before samples are processed.

6.2 BIOLOGICAL EFFECTS

1. The collection of four replicate 0.06-m^2 van Veen grab samples enabled an adequate assessment of benthic community structure in Commencement Bay. Use of a 0.06-m^2 grab is recommended for future studies because of substantial cost savings (per sample) over a standard 0.1-m^2 grab.

2. Statistical analyses of the abundances of major groups of benthic macroinvertebrates (i.e., total abundance, Poly-

chaeta, Mollusca, and Crustacea) enabled areas of toxic effects to be identified. Evaluation of community structure based on species-level identification was useful in assessing differences among areas and in identifying probable causes (e.g., toxicity vs. organic enrichment) of modified benthic assemblages.

3. Selection of an adequate reference area is critical to evaluation of effects on benthic macroinvertebrates because of the overriding influence of sediment particle size on these assemblages. If detailed information on the sediment characteristics of the study area and candidate reference sites is not available, a reconnaissance survey should be conducted to ensure that adequate reference sites are available for the range of sediment characteristics in the study area.

4. The current study design enabled detection of statistically significant differences in fish hepatic lesion prevalences at the waterway level. Therefore, the use of demersal fish histopathology as an effects variable can provide a relatively localized assessment of biological effects.

5. Fish histopathology is an important independent indicator of biological effects because it does not correlate with effects on benthic macroinvertebrates or sediment toxicity.

6. Analyses of contaminants in English sole muscle tissue enabled assessment of spatial differences in bioaccumulation on a waterway basis, and in some cases within a waterway. The site-specific co-occurrence of several compounds in sediments and fish muscle tissue indicates that these studies provide a reliable assessment of bioavailability of sediment contaminants.

7. Use of five fish tissue samples per area results in a relatively poor statistical power in detecting spatial differences in tissue contaminant levels. However, for important compounds such as PCBs, the current study design enabled detection of statistically significant elevations in tissue concentrations on a waterway basis that were <5 times the reference concentration.

8. Larger English sole (e.g., >300 mm total length) should be used for bioaccumulation studies to ensure that sufficient muscle tissue is available for full-scan priority pollutant analyses.

9. Full-scan priority pollutant analyses of fish livers are not recommended because of small sample sizes and the considerable sample processing required to reduce interferences from high lipid content. Analyses of fish livers may be useful, however, for specific substances such as PCBs or selected metals (e.g., mercury).

10. Volatile organic compounds were bioaccumulated by English sole in several areas of Commencement Bay. These compounds (especially tetrachloroethene) should be analyzed for in fish tissues if there is evidence of high sediment or water contamination.

11. The oyster larvae bioassay is not recommended for future studies of sediment contamination because of response similarity with the amphipod bioassay, confounding problems with high mortalities, and effects of low dissolved oxygen. To a lesser degree, the amphipod bioassay may also be subject to interpretive difficulties because of oxygen depletion during exposure to highly organically enriched sediments.

12. Amphipod bioassay mortalities may result from particle size effects where the sediments are >80 percent fine-grained materials (i.e., silt plus clay). In those cases, sediment chemistry data should be carefully reviewed, and the influence of particle size should be evaluated before concluding that observed mortalities are caused by toxic contamination.

13. Conducting sediment bioassays and benthic infaunal analyses at each sediment chemistry station would have enabled a much better determination of quantitative relationships [toxicity and benthic apparent effect thresholds (AET)].

14. Four kinds of hepatic lesions (neoplasms, preneoplasms, megalocytic hepatosis, and nuclear pleomorphism) should be used in assessing histopathology in English sole.

15. For liver histopathology studies, 60 fish per area is the minimum number required to obtain reasonable statistical discrimination (i.e., to detect differences in lesion prevalence of 10-15 percent) among areas.

16. English sole used for liver histopathology studies should be >225 mm total length and >3 years of age. All samples should also be age-corrected prior to statistical evaluation of spatial or temporal differences in lesion prevalence.

6.3 DECISION-MAKING APPROACH

1. The defined decision-making approach, incorporating five independent measures of contamination, toxicity, and biological effects (i.e., sediment chemistry, sediment bioassays, benthic macroinvertebrates, fish bioaccumulation, and fish liver histopathology), enabled an objective and defensible identification and prioritization of problem areas associated with toxic chemical contamination. For this purpose, the latter two measures were used only as average values at the waterway level. The first three measures were also used as site-specific indicators to define the spatial extent of problems areas. The use of this assessment approach ("pentad approach") is recommended in other studies of sediment contamination.

2. Using toxicity and benthic AET, the extent of problem areas could be defined and potential problem chemicals at each site could be identified. Although AET are first approximations and not proof of cause-effect relationships, the AET provide empirical evidence that helps define and narrow the "gray zone" between a clear no-effects level and an apparent effect level for different chemicals. Identifying chemicals above AET values allowed source identification efforts to focus on those problem chemicals.

6.4 SOURCE IDENTIFICATION

1. Normalization of chemical concentrations to organic carbon or percent fine-grained material was sometimes useful in giving additional source information not conveyed by dry-weight concentrations in sediments. At the most severely contaminated sites, however, gradients in dry-weight concentrations were sufficient to indicate potential sources. Normalization of chemical concentrations enabled a better definition of groups of chemicals with similar environmental distributions and potentially similar sources. Because organic carbon and grain size probably affect the bioavailability of chemicals, the continued evaluation of normalized data in developing quantitative relationships is also recommended.

2. Contaminant loading data were limited for most potential sources, and for many others, no loading data existed. This data gap impaired source evaluation and allowed prioritization of potential sources on a relative basis only. Collection of additional source data is recommended in all problem areas. These data should cover at least critical problem chemicals, with detection limits that reflect representative flow conditions and suspended solid loadings from each source (i.e., consider the detection limits of the resulting loading for each chemical). Additional measurements of flow rates are needed to establish reliable estimates of the relative magnitude of sources.

   Estimates of historical contaminant loadings are even more uncertain than those for ongoing sources. Contaminant loadings in a problem area may have changed over time because different industries occupied the site or because changes in industrial activities altered the contaminant loadings in the discharges. Therefore, additional review of historical industrial and land use practices are recommended, with a focus on the problem chemicals and products that contain these chemicals.

3. In several of the problem areas it was difficult, or impossible, to determine whether the contamination observed in the sediments was from historical or ongoing sources. Data gaps that prevented this determination included inadequate or missing source loading data for the problem chemicals, and inadequate sedimentation rate estimates for the individual waterways.

Additionally, disturbance from dredging activities within the problem areas complicated the assessment of relative depositional periods of the problem chemicals. This was the case for PCBs in Hylebos Waterway Segment 2. Source investigations have revealed little about whether PCBs are from historical or ongoing sources.

4. Sediment accumulation rates in major problem areas in waterways such as City and Hylebos obviously differ substantially from one another, but are needed to address remedial alternatives. Representative rates are unknown. While conditions in these waterways present problems in applying dating techniques, dating of selected cores (e.g., by the Pb-210 technique) is recommended to determine if gross estimates of sediment accumulation rates ($mg \cdot kg^{-1} \cdot yr^{-1}$) may be possible in these areas.

7. REFERENCES

Becker, D.S. 1984. Resource partioning by small-mouthed flatfishes (Pleuronectidae) in Puget Sound, Washington. Ph.D. Thesis. University of Washington School of Fisheries, Seattle, WA. 138 pp.

Brown and Caldwell, and E.V.S. Consultants. 1983. Site safety plan, tasks 3 and 4. Commencement Bay Nearshore/Tideflats Cooperative Agreement. Brown and Caldwell, Seattle, WA 32 pp.
BRCA0050

Brown and Caldwell, and E.V.S. Consultants. 1984. Quality assurance project plan for Commencement Bay Nearshore/Tideflats Remedial Investigation, Task 3. Prepared for Washington State Department of Ecology, Olympia, WA. Brown and Caldwell, and E.V.S. Consultants, Seattle, WA. 59 pp.

Fowler, S.W. 1982. Biological transfer and transport processes. In: Pollutant Transfer and Transport in the Sea, Volume II. G. Kullenberg (ed). CRC Press, Boca Raton, FL. 65 pp.

Gahler, A.R., J.M. Cummins, J.N. Blazevich, R.H. Rieck, R.L. Arp, C.E. Gangmark, S.V.W. Pope, and S. Filip. 1982. Chemical contaminants in edible, non-salmonid fish and crabs from Commencement Bay, Washington. EPA-910/9-82-093. U.S. Environmental Protection Agency, Region 10, Seattle, WA. 118 pp.

Malins, D.C., B.B. McCain, D.W. Brown, A.K. Sparks, and H.O. Hodgins. 1980. Chemical contaminants and biological abnormalities in central and southern Puget Sound. NOAA Technical Memorandum OMPA-2. National Oceanic and Atmospheric Administration, Boulder, CO. 295 pp.
MALI002F.

Malins, D.C., B.B. McCain, D.W. Brown, A.K. Sparks, H.O. Hodgins, and S.L. Chan. 1982. Chemical contaminants and abnormalities in fish and invertebrates from Puget Sound. NOAA Technical Memorandum OMPA-19. National Oceanic and Atmospheric Administration, Boulder, CO. 168 pp.
MALI003F

Malins, D.C., B.B. McCain, D.W. Brown, S.L. Chan, M.S. Myers, J.T. Landahl, 1984. Chemical pollutants in sediments and diseases of bottom-dwelling fish in Puget Sound, Washington. Environ. Sci. Technol. 18:705-713.

Orlob, G.T., D.R. Peterson, and K.R. Jones. 1950. An investigation of pollution in Commencement Bay and the Puyallup River System. State of Washinton Pollution Control Commission. Technical Report No. 8. 26 pp. plus appendices.

Pierce, D., D. Noviello, and S. Rogers. 1981. Commencement Bay seafood consumption study-preliminary report. Tacoma-Pierce County Health Department, Tacoma, WA.

Tetra Tech. 1983. Site safety plan guidelines for Commencement Bay Nearshore/ Tideflats Remedial Investigation. Tetra Tech, Inc., Bellevue, WA.

Tetra Tech. 1984a. A decision making approach for the Commencement Bay Nearshore/Tideflat Superfund project. Prepared for the Washington State Department of Ecology. Tetra Tech, Inc., Bellevue, WA. 64 pp.

Tetra Tech 1984b. Sampling and analysis plan report prepared and modified by Brown and Caldwell and E.V.S. Consultants for the Commencement Bay Superfund Project, Washington Department of Ecology. 43 pp.

U.S. Environmental Protection Agency. 1984. Health assessment document for tetrachloroethylene. External review draft report. U.S. EPA Office of Health and Environmental Assessment, Washington, D.C.